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ABSTRACT

This unit is concerned with geology of the sea floor; it is designed for secondary school students. Included in this unit are teacher background materials, student activities, transparency masters, maps, and answers to student activities. Changes taking place in the sea floor and variables influencing these changes are emphasized. (RH)

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SEA FLOOR SPREADING

A Learning Experience for
Coastal and Oceanic
Awareness Studies

Produced by

MARINE ENVIRONMENT CURRICULUM STUDY
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Please send evaluations
of learning experiences
to

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TITLE: SEA FLOOR SPREADING

*CONCEPT: I.A.

I. The earth is a finite natural system.

A. THE PROPERTIES AND INTERACTIONS OF WATER, AIR, AND THE
PHYSICAL EARTH SET THE LIMITS OF THE NATURAL SYSTEM.

**MARINE CONCEPT: 2.33

2. The oceans interact with the earth and its atmosphere.

2.3 Energy is transferred wherever ocean and land or
atmosphere meet.

2.33 SUBSURFACE TOPOGRAPHY IS CONSTANTLY CHANGING.

GRADE LEVEL: 9-12

SUBJECT: Earth Science, Marine Science

PERIODS: Various

AUTHOR: Hull

*From A Conceptual Scheme for Population-Environment Studies, 1973. Cost \$2.50.

**From Marine Environment Proposed Conceptual Scheme, 1973. No charge.

Both conceptual schemes are available from Robert W. Stegner, Population-
Environment Curriculum Study, 310 Willard Hall, University of Delaware,
Newark, DE 19711.

R676

TEACHER INTRODUCTION

"Sea Floor Spreading" is a learning experience written so that the student can arrive at the theory of plate tectonics in a logical manner--much the same way it was actually done by scientists. It is designed so that the students may work independently toward the completion of the unit. However, the learning experience can easily be adapted to a lecture-discussion approach. If a lecture-discussion format is used, only the worksheets and lab investigations should be distributed to the students; the readings should be retained and presented by the instructor.

In this learning experience the student will be engaged in learning terminology used in oceanography, locating numerous topographic features associated with the ocean basin, developing distribution patterns for earthquakes and ocean sediments, learning how seemingly unrelated data are tied together to develop a theory, and speculating on future movements of the earth's crust.

At the conclusion of this learning experience the student should be able to:

1. describe what a physiographic diagram is and how it is constructed.
2. define terms used to identify topographic features of ocean basins.
3. locate ocean ridges, island arcs and deep-sea trenches on a map of ocean basins.
4. describe the way in which topographic features are formed in the ocean basins.
5. identify the "puzzle fit" relationship of several large land masses and how this has led to the development of the theory of continental drift.
6. describe convection currents, their causes, and their possible influence on the topography of the ocean basin.
7. identify position relationships of certain topographic features and explain what they suggest about movement of the crust.
8. define terms used in the study of earthquakes, such as epicenter, focus and seismograph.
9. plot the distribution of earthquakes around the world and within the crust.
10. describe the relationship between earthquake distribution and topographic feature distribution.
11. explain what earthquake distribution suggests about crustal movements.
12. describe the relationship between the age of sediments and their distance from ridge axes.
13. state the age of the ocean basins relative to the age of the earth.
14. define magnetic reversal and explain its effect on iron-rich igneous rocks.
15. describe how magnetic reversals relate to plate tectonics.
16. identify present crustal plates and their movements.
17. state the relative ages of present ocean basins.
18. speculate on future movements of crustal plates.

TEACHER BACKGROUND INFORMATION

The learning experience itself serves as background material for the instructor. Therefore, an additional write-up including greater detail on the theory of plate tectonics is not provided. Excellent references for this purpose are provided on pp.33-34. The four National Geographic maps referred to on p. 34 provide excellent illustrations of the ocean floor and should be used with this learning experience. If they are not available from your school library, the maps are available from Population-Environment Curriculum Study, 310 Willard Hall Education Building, University of Delaware, Newark, DE 19711 at a cost of \$1.50 each or \$6.00 for the set of four.

The answers to the questions asked in the student material, notes on procedure, the purpose of each of the investigations, and the figures completed the way the students are asked to complete them are provided in the Teacher's Guide on pp.28-49.

SEA FLOOR SPREADING

Student Material

"Sea Floor Spreading" is a learning experience designed to help you arrive at the theory of plate tectonics logically--in much the same way that it was actually done by scientists. This theory is concerned with the nature of changes in the earth's crust. Your teacher will probably encourage you to do much of this learning experience independently. During your study of this unit you will:

1. learn terminology used by oceanographers.
2. locate numerous topographic features in the ocean basin.
3. develop distribution patterns for earthquakes.
4. learn how seemingly unrelated data are often tied together to develop a theory.
5. speculate on future movements of the earth's crust.

INTRODUCTION

When we sail ~~on~~ the open ocean we see nothing but water from horizon to horizon. We may ask ourselves: What is it like underneath the ocean--on the ocean floor? Is it monotonous and unchanging in its surface topography for thousands of square miles? Or does it have a landscape as varied as that found on dry land? Before the invention of the echo sounder, the answers to these and many other questions could only be inferred from the widely separated readings taken with a sounding line. Today, with the use of the more sophisticated echo sounder, a rather complete profile of the features of the ocean floors can be constructed. From analysis of the data, we find that the ocean basin is not an area of monotonous topography. On the contrary, the topography of the ocean floor is every bit as varied as that found on the continents. The features of the ocean basins range from high mountains to deep canyons. These features are located in all the oceans of the world and seem to display some pattern and regularity in their distribution. Some even appear to connect as if they were a continuous feature, winding around the globe in an apparent but irregular path.

Knowing the features that make up the topography of the ocean basins only presents more difficult questions to be answered. Perhaps the most difficult question of all is about the origins of these features. How did these features evolve? What forces are responsible for their formation? Although the study of the ocean floor is still only fragmentary, in recent years there has been more evidence for the answers to these questions produced than in any other phase of oceanography.

SUBMARINE TOPOGRAPHIC FEATURES

Now that the echo sounder has replaced the sounding line, a rather detailed contour map showing the topography of the ocean basin can be made. Despite this technological capability, very few areas of the ocean floor have been mapped in detail. In areas where detailed survey data are not available, a general impression of the ocean floor can be obtained from a physiographic diagram.

Data for the construction of this diagram are compiled from the continuous sea bottom profile measurements along a ship's path. When completed, the physiographic diagram suggests the general shape of the ocean floor; i.e., whether the ocean bottom is a smooth plane, a series of hills, a mountain range, or isolated peaks on a flat ocean bottom. Obviously the accuracy of the physiographic diagram depends on the number and density of the tracking paths. The more paths a ship makes in one area, the more complete the resulting physiographic diagram will be. Analysis of physiographic diagrams of the oceans of the world shows that the topography of the ocean floor is at least as varied as that of the continents.

Like the topographic features we are familiar with on the surface of the earth, the features of the ocean basins are classified by size, shape, origin, etc. The following terms and definitions apply to topographic features we will study in this section.

Guyot - A flat-topped seamount, also called a tablemount.

Island arc - A group of islands having a curving arc-like pattern.

Island chain - An elongate series of isolated islands separated by a relatively level sea floor plain.

Ridge - An elongate elevation on the deep-sea floor with steep sides and irregular topography.

Rise - A broad elevation on the ocean floor with gentler and smoother sides than those of a ridge.

Seamount - An isolated or comparatively isolated submerged elevation arising from the deep-sea floor. It has comparatively steep slopes and relatively small summit area.

Seamount chain - An elongate series of seamounts or guyots separated by a relatively level plain.

Trench - A deep, long and narrow depression of the deep-sea floor. It has relatively steep sides.

1. Figure 1, Submarine Topographic Features, p.13, is a physiographic diagram of a hypothetical ocean basin. Label the features shown from the list of terms given above.
2. Examine Figure 2, Ridges on the Ocean Basins, p.14 (this map includes both ridge and rise features found in the oceans) or the National Geographic maps. Generally speaking, would you say that the ridges are a continuous or discontinuous system of submarine mountains?
3. Generally speaking, where are the oceanic ridges located within the ocean basins?
4. Now examine Figure 3, Island Arcs and Deep-Sea Trenches, p.15. Does there appear to be any relationship between the location of the island arcs and the location of deep-sea trenches? If so, explain in detail what this relationship is.

As mentioned, seamounts are isolated submarine hills with a typical volcano shape. Their shape and the basaltic rocks usually dredged from their surfaces suggest a volcanic origin--that is, they were all probably volcanoes at one time in the past.

When the seamounts have flattened tops, they are called guyots. Since volcanic peaks are pointed, how can the flat-topped guyots be explained? When the tops of these features are dredged, we find typical reef flora and fauna, volcanic rocks, and sediments that indicate the guyot was once close to sea level. With this evidence, scientists theorize that this feature was once a seamount with its peak very close to sea level or a volcanic island with its peak slightly above sea level. In either case, at sea level the wave action eroded the peak of the volcano and leveled it to slightly below the sea level. Here it became a natural habitat for coral. See Figure 4, Development of a Guyot, p. 16

5. What does the existence of guyots far beneath the surface of the ocean indicate about the past level of the ocean?

Finally, examine Figure 5, Island and Seamount Chains, p. 17. Since most of the seamount chains and island chains appear to be in the Pacific Ocean, the questions asked below will pertain to the Pacific Ocean only, unless stated otherwise.

6. In what general direction do most of the chains appear to be oriented? (Use compass directions.)
7. Does there appear to be any differences from one end of the chain to the opposite end in terms of land size and/or type of feature? That is, in one chain does the type of feature change from one end to the other? Explain. (For a detailed drawing of the Pacific Ocean floor, see the map included in National Geographic, October, 1969, Vol. 136, No. 4.)
8. What might this suggest about the relative age of the islands, seamounts, or guyots from one end of the chain to the other? Explain.

THE EARTH'S PUZZLE--Part 1

Study any of the world maps included in this learning experience and/or a globe.

1. Do you see any relationships between the shape of the continents? Explain. Turn to Figure 6, Puzzle Parts, p. 18, and cut out each of the parts along the solid lines. Now try to put the parts together so that they all fit together forming one big piece.
2. What do the puzzle parts represent? What might this suggest about the history of our present day continents?

Did the continents once fit together like a gigantic jigsaw puzzle and then gradually move apart to assume their present configuration? This idea of continental drift is not new. In fact, the correspondence between the western coastline of Africa and the eastern coastline of South America was known to most explorers several hundred years ago. In 1620, Sir Francis Bacon noted the similarities and reasoned that they were more than accidental in nature. However, he was unable to give any explanation for the similarities.

Since then, various ideas and theories have been proposed to explain the natural fitting of the east coast of the Americas and the west coast of Africa and Europe. Not until 1912 was there a truly plausible explanation for this. Alfred Wegener, a German geologist and meteorologist, suggested that all the world's continents once fit together in a single super-continent called Pangaea (which is Greek for "all lands").

Wegener fitted the continental shield together roughly the way you fitted the pieces of Figure 6 together. He supposed that the continents began to drift to their present positions between 100 million and 200 million years ago. In his theory, however, he failed to state what forces were responsible for such large-scale movements.

Thus far, we have examined various types of submarine topography, the locations of these topographic forms around the globe, and the continents' apparent "puzzle fit" relationship. Let us now re-examine Figures 2, 3 and 5, the maps showing the positions of the various features discussed.

3. Can you see or develop any relationship between the locations and types of submarine features we have examined and Wegener's idea of drifting continents?

To get a better understanding of what the topographic relationships suggest, particularly the one between the ridges and trenches, do the following investigation:

Fill a large beaker with about two inches of water and place a bunsen burner at low flame under one edge of the beaker. Put a drop of dye in the water directly over the flame.

4. Describe the movement of the dye in the water. Explain why the dye is moving in this manner.

Now place another bunsen burner at low flame under the opposite edge of the beaker and add another drop of dye to the water directly over it.

5. Describe the total movement of the water in the beaker. Use diagrams if you wish.

What you see is a convection current. A convection current is a circulatory motion caused by non-uniform temperatures. A heated substance rises and moves along an upper boundary. In doing so, it begins to cool, becomes denser and sinks.

6. On Figure 7A, Convection Current Circulation, p. 19, label the areas where the convection current is the warmest and where it is the coolest.

Now that we know the general circulation of a convection current, what do you think would happen to a flexible material floating on top of a liquid subject to currents?

7. Look at Figure 7B, Effects on Crust, p. 19. What effect does the convection current circulation have on the layer of material on top of it?
8. If the material on top is floating, in which direction is it floating? Indicate this with arrows.

9. We could consider the interior of the earth below the crust as a very thick liquid with very slow convection currents. What would this suggest about the type of topography to be found over an area where the convection moves upward under the crust? where it moves downward under the crust?
10. What is the relationship between Wegener's concept of moving continents and the positions of the ridges (the Mid-Atlantic Ridge in particular)?
11. On Figure 8, Composite Map of Ridges, Trenches, Island Arcs and Island Chains, p. 20, draw several arrows in pencil to indicate the direction of movement of some crustal plates.

The little bit of evidence presented thus far is impressive at best. In no way is it conclusive and should only be treated as theory--not fact.

12. What are some additional observations that would have to be made before a theory of moving continents could be proven or at least strengthened?

THE CRUST THAT CRACKS

Most people think of the earth as solid and permanent. Yet scientists estimate that anywhere from 1,000 to 5,000 earthquakes occur in different parts of the world each day. What is an earthquake? Quite simply, an earthquake is a sudden movement of the earth's crust caused by volcanic activity or the shifting of the earth's surface. Most of the movement is very minor; however, a sudden and spectacular change occasionally does result when forces within the crust have built up too rapidly to be relieved by a series of small tremors. This is when the most damage occurs.

When an earthquake occurs, the movement causes waves of various types to be sent out in all directions from the focus, the location of the earthquake. These waves can be detected with a sensitive instrument called a seismograph. By a method known as triangulation, analysis of the data from three or more seismographs can pinpoint the location and time of occurrence of any earthquake on the earth. In addition, the depth and magnitude of the earthquake can be measured.

The information needed to complete the following investigation can be found in Figure 9A, Earthquake Data, on p. 21. This information can be obtained from the Delaware Geological Survey located on the University of Delaware campus or from the Smithsonian Institution Center for Short-Lived Phenomena in Cambridge, Massachusetts. The data include the epicenter location, time of occurrence, depth and magnitude of earthquakes. The surface location, or epicenter, is the geographic point on the earth's surface directly above the focus of the earthquake.

Using the information in Figure 9A, plot the epicenters of all the earthquakes on Figure 9B, Earthquake Distribution Map, p. 22. NOTE: In plotting the earthquakes, it will be helpful if you divide them into three groups according to focus depth and plot each group with a different color or symbol. The following depths can serve to divide the groups.

FOCUS DEPTHS:	Shallow	0 Km to 69 Km
	Intermediate	70 Km to 300 Km
	Deep	301 Km to 700 Km

1. What is the general pattern of earthquake distribution around the world? Be specific.
2. Where did the greatest number of earthquakes occur?
3. Referring back to your answer for #2, describe the distribution of shallow, intermediate, and deep focus earthquakes in this region.
4. What does the occurrence of earthquakes suggest about the nature of the crust in those areas where earthquakes occur?
5. Compare your Earthquake Distribution Map (Figure 9B) with Figure 2, Ridges on the Ocean Basins, p. 14 or the National Geographic sea floor maps. Does there seem to be any relationship between the locations of the earthquakes and the locations of any ridges?
6. If there is a relationship between ridges and earthquakes, which type of earthquake is most related to ridge locations? What does this indicate about the location of the movement which caused the earthquake?
7. Now compare your Earthquake Distribution Map with Figure 3, Island Arcs and Deep-Sea Trenches, p. 15, or the National Geographic sea floor maps. Is there any relationship between the locations of island arcs and trenches and the distribution of earthquakes? If so, explain the relationship by describing the location of each type of earthquake (shallow, intermediate, and deep) relative to the island arcs and trenches. What does this information suggest about the location of the movement which caused these earthquakes?

To get a more thorough understanding of the nature of earthquake distribution, construct an earthquake distribution profile on Figure 10B, Earthquake Distribution Profile, p. 23, using the data given in Figure 10A, Earthquake Profile Data, also on p. 23. When all the earthquakes are plotted on the profile, draw a line through the points to represent the general trend of the earthquake foci.
8. Using your profile, describe the distribution of the earthquakes below the surface.
9. Does the earthquake zone dip under the continents or under the ocean basins?
10. What does this suggest about the direction of movement below the crust in these areas?
11. Examine your map of earthquake distribution and identify four areas in the world where earthquakes are distributed similarly to the distribution shown on the profile. Is there any topographic feature found in all these areas? Explain.

OUR YOUTHFUL OCEANS

It is said that all rivers eventually flow to the oceans. These rivers, which start far inland as small springs and streams, erode and carry much sediment with them on their journeys. In fact, most of the materials that are weathered and eroded from the land eventually reach the oceans and are deposited in some part of the ocean basin. To study the sediments on the ocean basin in detail, core samples must be taken. This is done with a heavily weighted, long, thin pipe known as a corer. The corer is dropped into the ocean and after rapidly descending through the water, it penetrates the sediments on the ocean bottom. It is then pulled back on board the ship where the core of sediment is removed and examined.

Figure 11A, Sediment Data from the South Atlantic, p. 24, gives information on sediments collected and analyzed by the method described above. The table gives us the age of the sediments in millions of years, and the distance of the collection site from the Mid-Atlantic Ridge axis in kilometers (Km).

Graph the data given in Figure 11A on the graph paper provided in Figure 11B by letting the distance from the ridge axis in kilometers represent the independent variable. After all the sites are plotted on the graph, use a straightedge and draw a line which represents the general trend of the graph. Be sure the line begins at the origin.

1. According to your graph, what is the relationship between sediment age and distance from the ridge axis?
2. In the South Atlantic, where would you expect to find the oldest sediments--in the middle of the ocean, or near the continents?

In the South Atlantic, the oldest sediment recovered is 80 million years old; however, in none of the oceans have there been found any sediments older than 135 million years. And in all cases, the youngest sediments are found near ridge axes and the oldest are found nearest the continental margins.

An analysis of crustal rocks taken from ocean basins throughout the world indicates that none of the rocks are older than 200 million years. What does this suggest? This suggests that the crust under the oceans is probably not older than 200 million years. See Figure 12, Age of the Earth's Crust Under the Oceans, p. 25, to get a general idea of the distribution of crustal ages under the ocean.

3. Considering the estimated age of the earth to be 4.5 billion years, would you regard the age of the oldest crust beneath the oceans as being very old? Calculate what percentage the age of the oldest ocean basin crustal rock is of the total earth age.
4. What does this information suggest about the age of our present oceans?

Could you explain the existence of comparatively youthful oceans on an earth that is estimated to be at least 4.5 billion years old?

SLOW DOWN AND LOOK BACK

So far, we have investigated the "puzzle fit" relationships between various land masses; the types and distribution of earthquakes around the world and their apparent relationship to various submarine topographic features; and finally, the relationship between the ages of sediments and crustal rocks on the ocean basins and their distance from ridge axes. What does all this mean? How does it fit together? Or is it information that cannot be related at all?

What is the relationship between:

- a. the existence of island chains (and seamount chains) and their direction in the ocean basin?
- b. the existence of guyots and their position at the end of seamount chains?
- c. the shapes and puzzle fits of various large land masses?

- d. shallow focus earthquakes and ridges (or rises)?
- e. shallow, intermediate, or deep focus earthquakes and deep-sea trenches and island arcs?
- f. the ages of crustal rocks and sediments and their distance from ridge axes?
- g. convection currents and ridges and trenches?

Some of the questions posed above may not have clear-cut answers. To get a better picture of how the information is related, you may want to use a world map or the National Geographic maps to draw a composite map showing all the relationships studied so far.

The whole theory of continental drift hinges on one question: Do the continents move, or more correctly, does the crust move? When Wegener first proposed his theory, he suggested that only the continents moved, but he did not know why. Now we have compiled a considerable amount of information which might suggest that not only do the continents move, but entire blocks or plates of the crust move. Can the movement be proven and if so, what are the causes of such large-scale movements?

CONFIRMATION

The suggestion of crustal plate movement away from ridge axes and toward trenches in the ocean basins implies that new crust is being formed at the ridges and old crust is being consumed (subducted) at the trenches. Since the earth is neither expanding nor contracting in size, whatever is created in one area must be equaled by an amount being consumed in another area.

You know that the earth has a north and south magnetic pole. Thanks to these poles, we are able to use a compass for finding direction. The compass needle will always point toward the north magnetic pole and away from the south magnetic pole.

Certain rocks such as basalt and gabbro are rich in minerals which contain iron. These rocks are formed from hot molten material (magma) from within the earth; before they cool, the iron atoms align themselves in a north-south manner, in much the same way a compass needle does. When the rock cools, the magnetic alignment of the iron atoms becomes a permanent record of the earth's magnetic field at the time of that rock's formation.

It was learned recently (circa 1960) that the magnetic poles of the earth reverse themselves at the end of intervals averaging 450,000 years. The intervals have been as short as 50,000 years and as long as 700,000 years (this latter span is the period we are in today), and may be even longer. Are we due for another change?

Obtain two compasses, one bar magnet and two pieces of paper. Set them up as shown in Figure 13, Magnetic Reversals, p. 26.

Draw a line on each piece of paper one inch from the split between the tables and parallel to the split. Also, draw another line on each piece of paper at the split. Now draw an arrow in each of these areas indicating the direction in which the compasses are pointing.

Pull each piece of paper one inch out of the split and draw lines on each along the split. Place the compasses within the new one-inch strips and switch or reverse the magnet. See Figure 13B, p.26

1. What has happened to the direction in which the compasses are pointing?
2. If these papers were hot molten rocks which had just emerged from below the crust of the earth, what effect would a magnetic reversal have on the iron atoms in the rock?

Repeat the above procedure several more times.

3. Is the pattern of magnetic reversals on one side of the split identical to that on the opposite side of the split?

Examine Figure 14, World Map of Magnetic Reversals, p.27

4. What do the numbers on each side of the ridge axis indicate about the rate of spreading in each side of the ridge at a given point?
5. Does the data on magnetic reversals above confirm our earlier ideas about moving crustal plates? Explain.

THE EARTH'S PUZZLE--Part 2--Plate Tectonics

Science, like other fields of study, is replete with successes and failures. When the concept of Pangaea and continental drift was first proposed, few people thought it could be possible, and many simply laughed at the idea. In the past few years, however, geology has found itself in much the same position that astronomy was in during the time of Galileo and Copernicus. Thoughts and concepts on the nature of the crust and mantle are changing and books are being rewritten to include the new concept of plate tectonics.

Ask your teacher for a copy of Figure 15, Collected Data from World Ocean Basins. On Figure 15 determine the size and shape of crustal plates from the information given on the map. Outline the plates in pencil and identify each one with a number.

1. How many different crustal plates can you identify?

Study the map again and determine in which direction the plates are moving, or if they are motionless. Show the direction of any moving plates with an arrow drawn on the plate in the direction of movement.

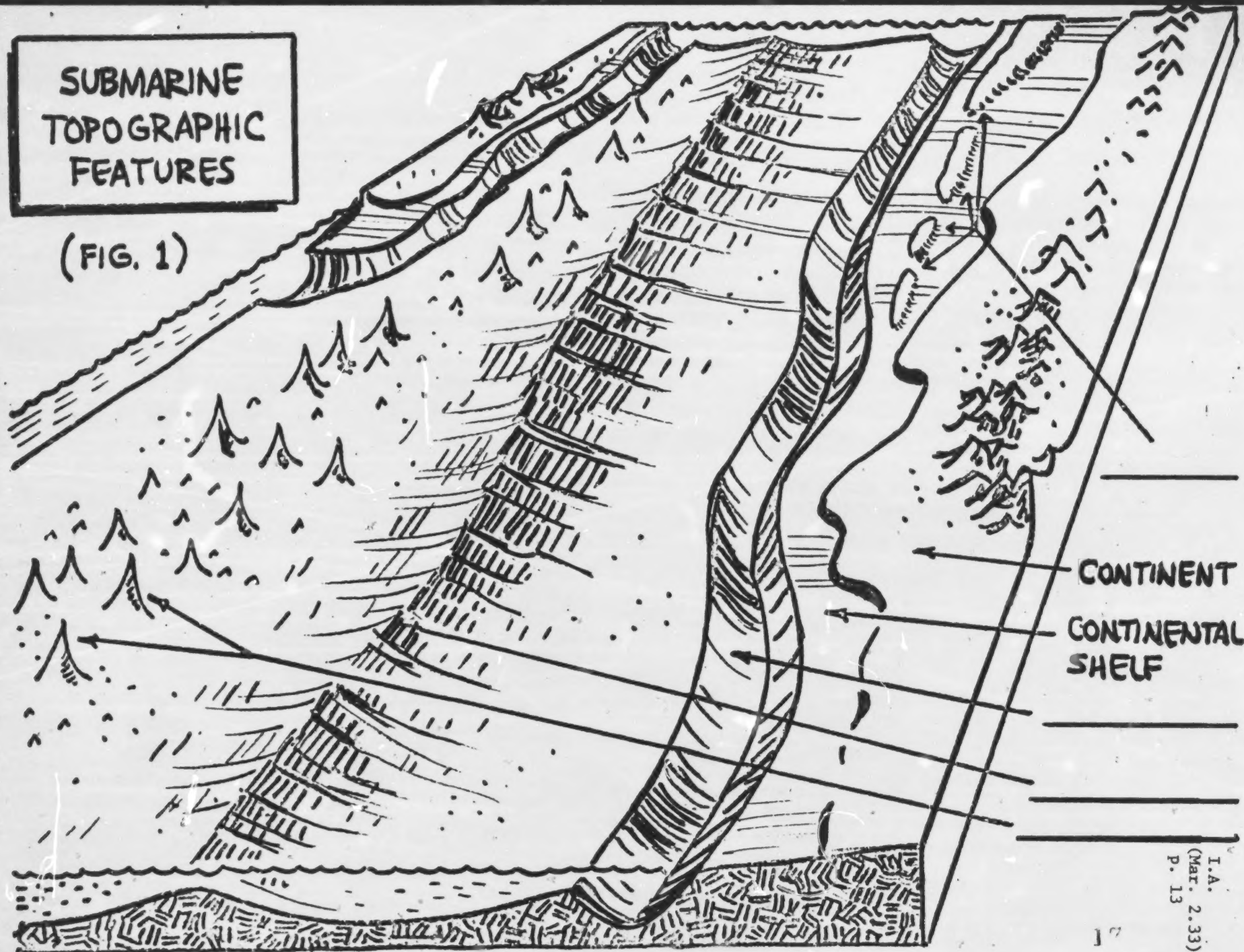
Ask your teacher for a copy of Figure 16, Movements for Crustal Plates. From Figure 16 determine which plates have fastest rates of movement and in which directions. The direction in which the arrows are pointing represents the direction the plate is moving. The length of the arrow represents the distance the plate will move in the next 50 million years.

Now, using the puzzle parts from Figure 6, p.18 determine the positions of the continents 50 million years in the future. Cut out new parts if you feel you will need them to make your positions more accurate. After you have located all the future positions, outline them with a pencil to make the map permanent.

2. What is happening to the sizes of the different oceans? Be specific.
3. Of the two oceans, the Atlantic and the Pacific, which one is older? Explain your answer.

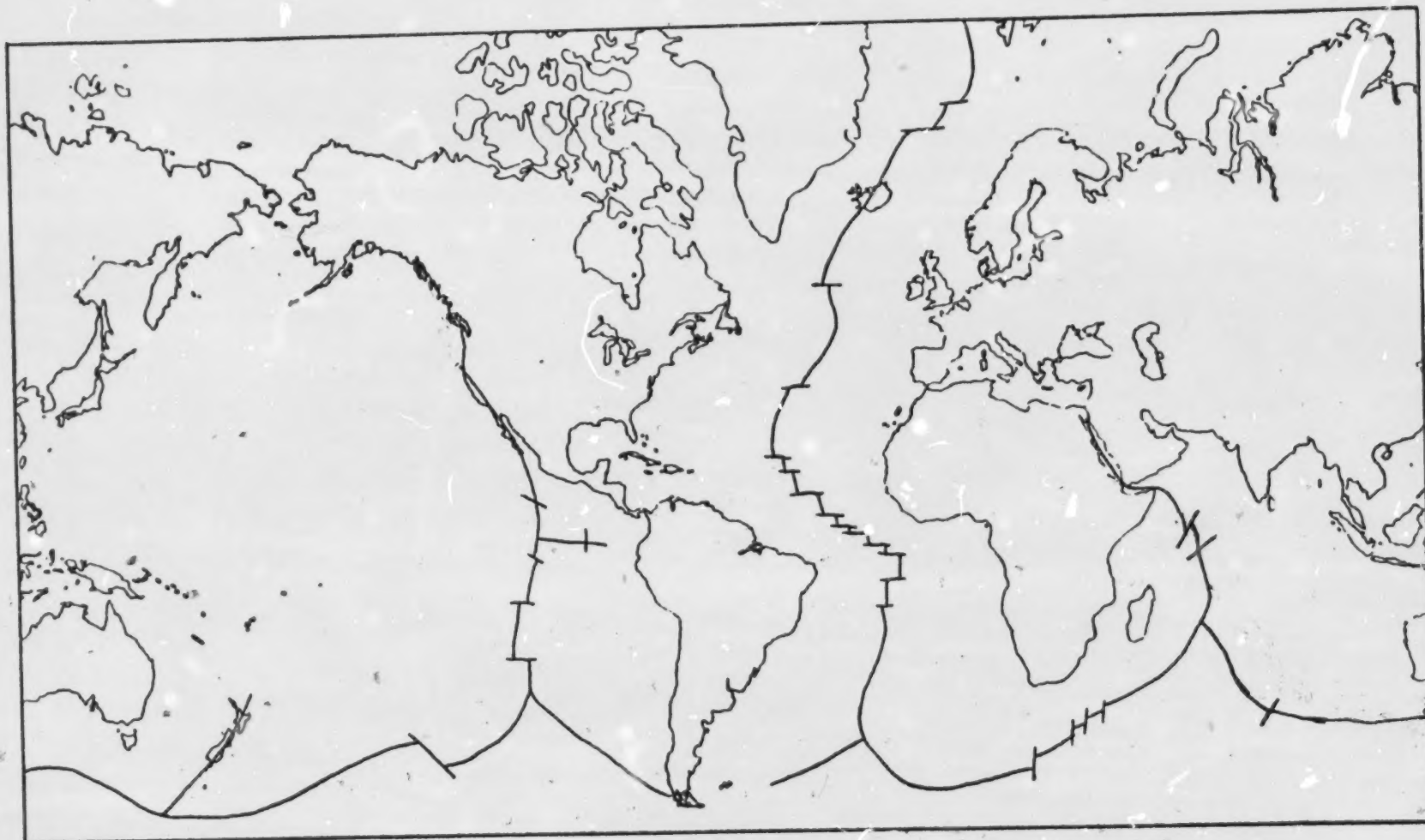
SUBMARINE TOPOGRAPHIC FEATURES

(FIG. 1)



CONTINENT
CONTINENTAL
SHELF

FIGURE 2: RIDGES ON THE OCEAN BASINS



Reference (11, pp. 280, 284, 293.)



Ridges with transform fault

I.A.
(Map. 2.33)
p. 14

FIGURE 3: ISLAND ARCS AND DEEP-SEA TRENCHES



----- Island arcs
▲▲▲▲ Trenches

(Reference (2, p. 56-57))

FIGURE 4: DEVELOPMENT OF A GUYOT

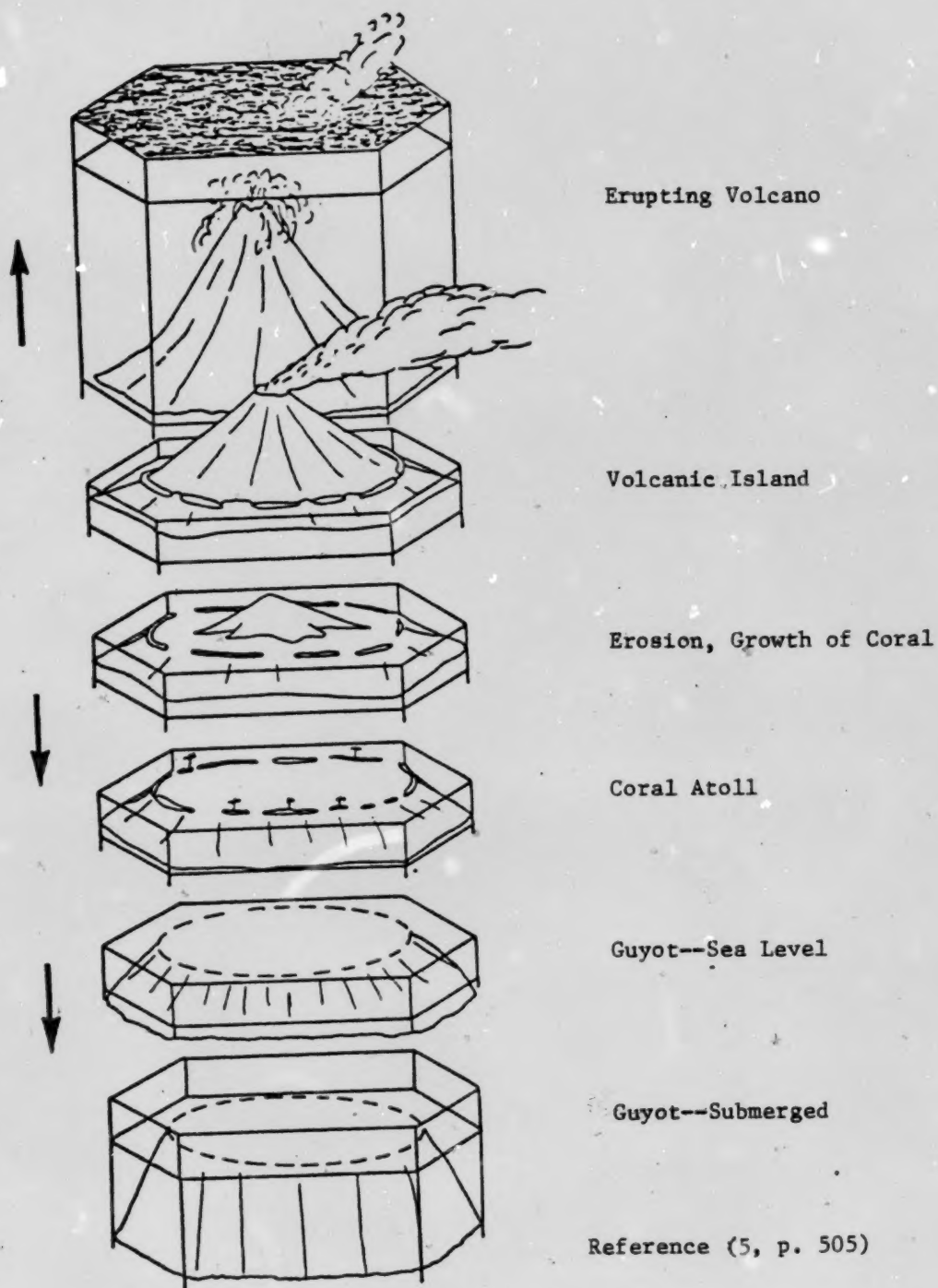
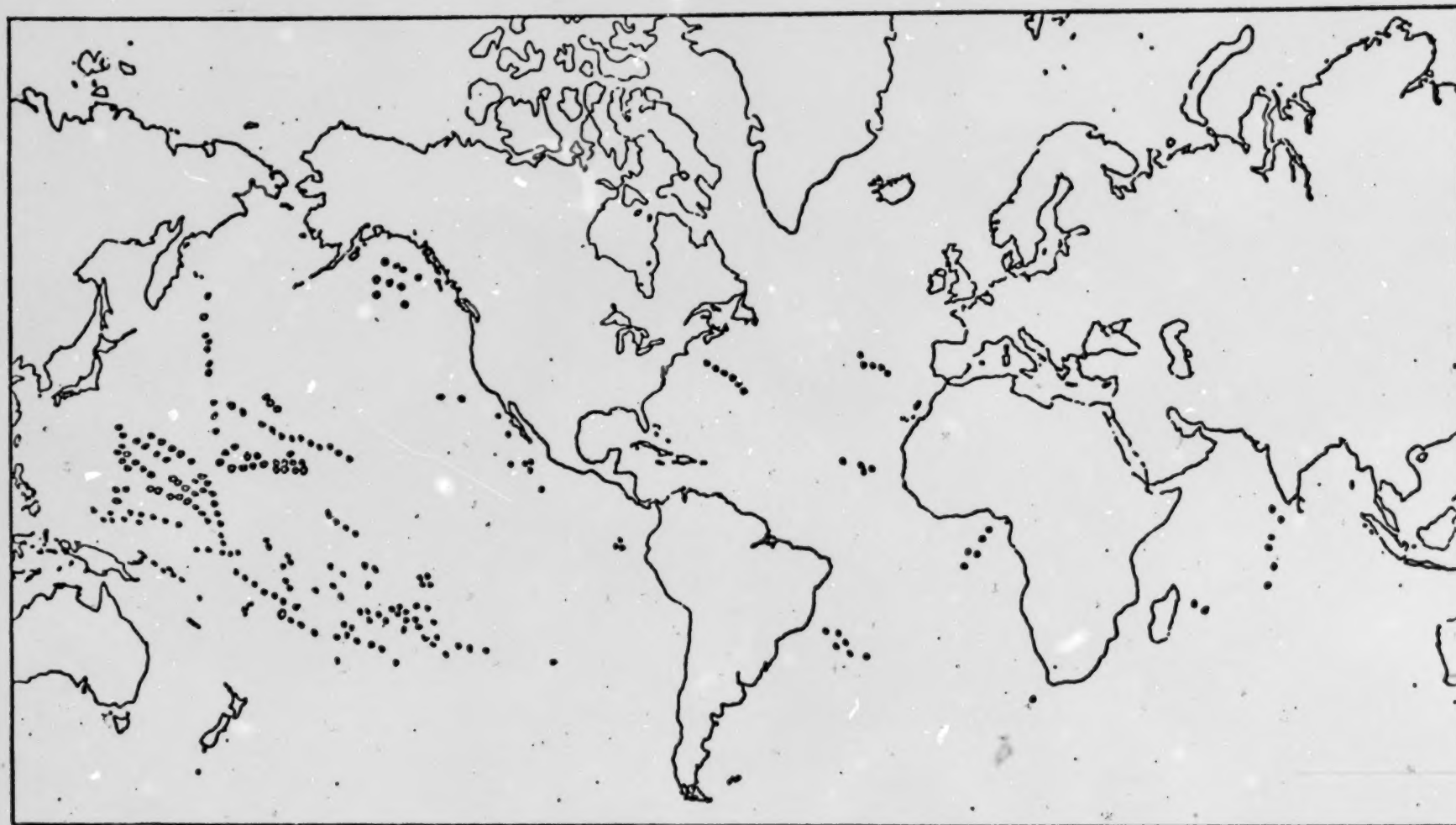


FIGURE 5: ISLAND AND SEAMOUNT CHAINS



..... Seamount Chains
 Island Chains

References (9, pp. 300-332)
 (5, pp. 496-497)

FIGURE 6: PUZZLE PARTS



FIGURE 7: CONVECTION CURRENTS

Figure 7A: Convection Current Circulation

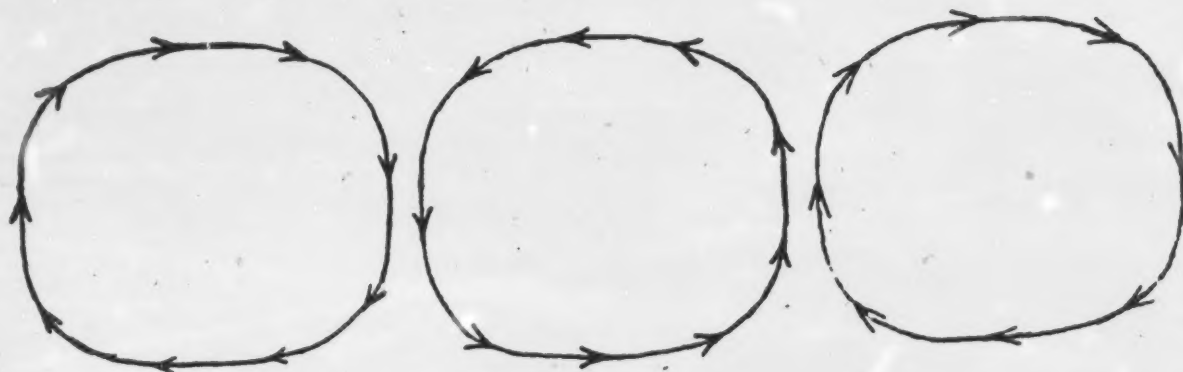


Figure 7B: Effects on Crust

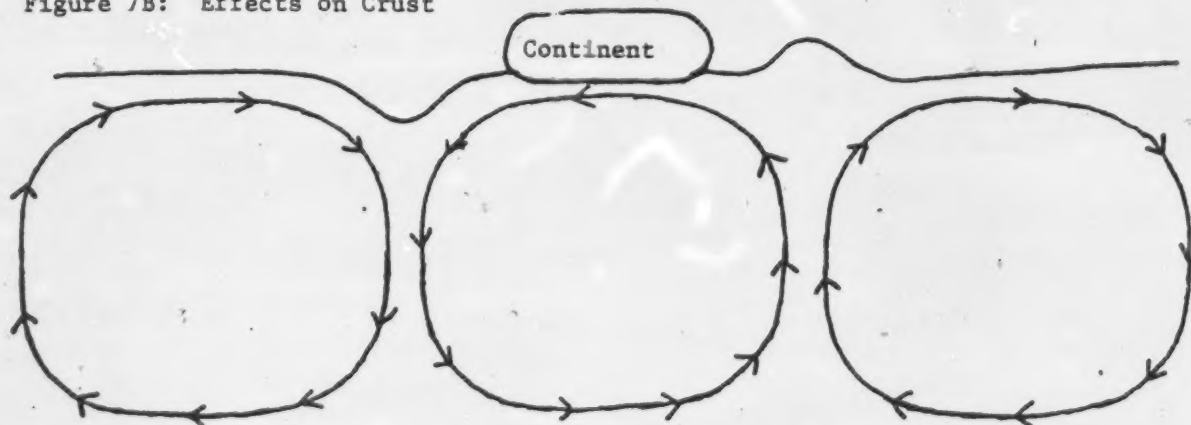
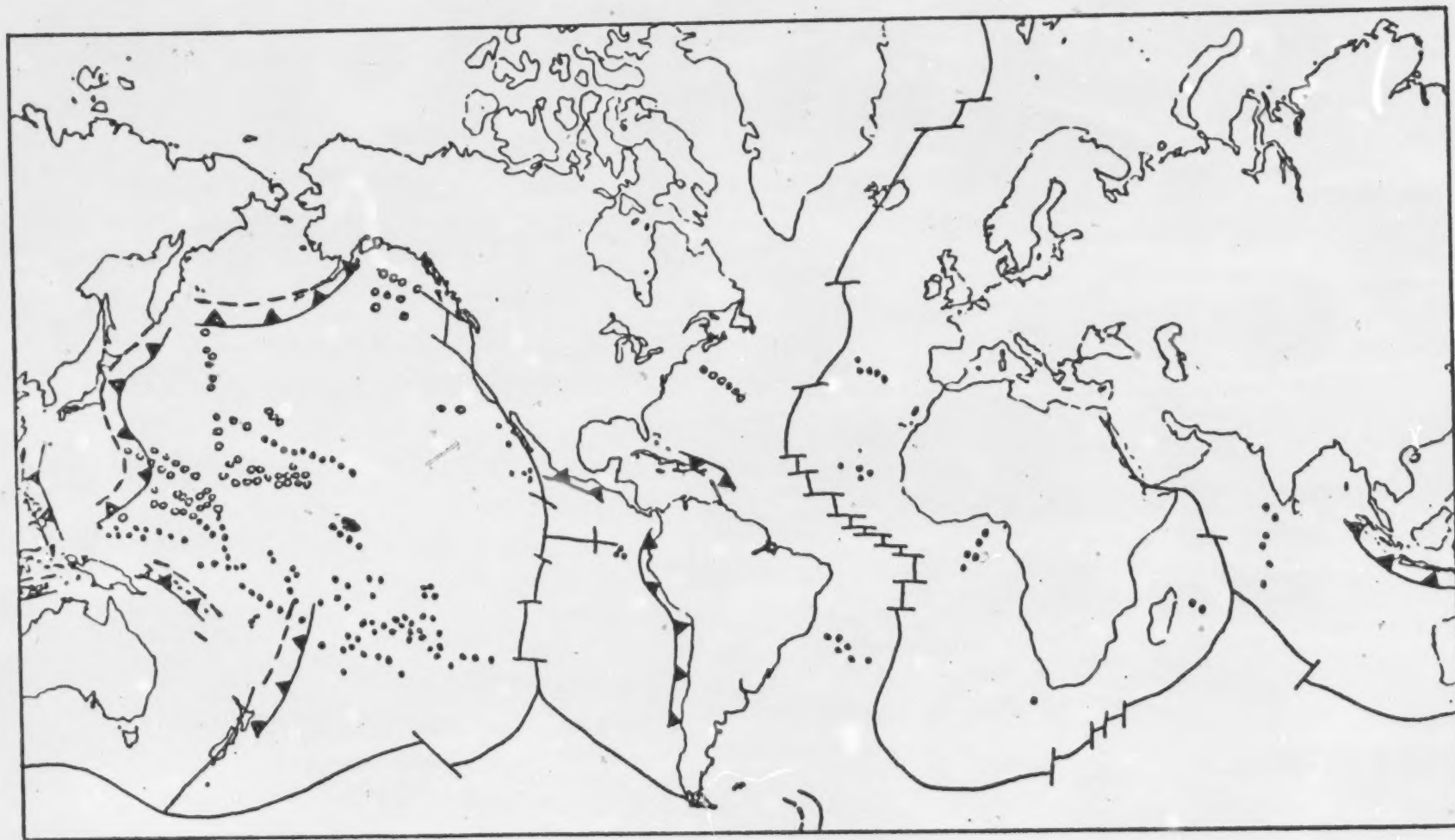


FIGURE 8: COMPOSITE MAP OF RIDGES, TRENCHES, ISLAND ARCS, AND ISLAND CHAINS



○○○○ Seamount chains
 ●●●● Island chains
 ─┼─┼─ Ridges with transform faults

- - - Island arcs
 ▲▲▲ Trenches

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FIGURE 9A: Earthquake Data

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The table below has been abbreviated to include only epicenter locations and depth of earthquake foci. Location coordinates are given by a number followed by either N, S, E, or W. Earthquake focus depths are expressed in kilometers. NOTE: The locations of the coordinates are not expressed in latitude and longitude, but in an easier-to-use Cartesian coordinate system. The only similarities between the Cartesian coordinate system used here and the latitude and longitude system are the major axes and the north, south, east and west directions from these axes.

COORDINATES	DEPTH	COORDINATES	DEPTH	COORDINATES	DEPTH
4N 12E	17	11N 31W	34	5N 59W	15
27N 1E	24	8N 29W	5	4S 51W	52
1S 15E	16	5N 28W	26	5S 49W	35
8S 14E	56	2N 27W	8	5S 41W	67
11S 12E	10	3S 27W	62	9S 42W	32
1S 24E	34	18S 9W	15	10S 43W	59
2S 26E	17	7S 27W	10	13S 45W	45
4S 28E	35	9S 28W	57	16S 43W	18
13N 3E	26	10S 27W	19	20N 36W	223
9N 18E	36	11S 28W	42	19N 40W	137
10N 20E	8	11S 26W	14	17N 42W	110
8N 23E	57	12S 18W	115	15N 45W	144
12N 6E	66	10S 18W	197	13S 47W	186
2S 29E	133	8S 18W	86	11S 45W	90
1S 27E	300	7S 18W	88	9S 44W	148
1N 26E	124	5S 18W	90	7S 43W	200
11N 19E	145	2S 20W	70	4S 48W	120
11N 22E	150	4N 22W	82	3S 50W	120
10N 24E	115	6N 26W	150	2N 59W	75
1N 30E	310	8N 28W	138	5N 60W	115
1N 28E	500	18S 10W	87	7N 54W	88
25N 5W	26	2S 18W	425	11N 55W	82
17N 7W	62	5S 16W	436	13N 53W	123
14N 7W	48	7S 16W	390	17N 44W	460
9N 11W	6	10S 16W	410	5S 43W	580
5N 11W	34	16N 34W	49	3S 48W	315
3N 9W	5	13S 34W	35	7S 45W	600
1N 7W	48	14S 33W	8	8S 45W	550
7S 5W	28	17N 39W	5	10S 46W	360
14S 5W	0	14N 43W	24	15N 53W	350
16S 2W	58	14N 46W	36	14N 55W	380
4S 21W	48	12N 52W	38	14N 57W	400
7S 19W	69	9N 54W	15	9N 56W	350
10S 19W	57	6N 52W	18	7N 56W	370
12S 20W	62	4N 52W	48	2N 60W	410
14S 19W	65	3N 53W	52	1N 21W	48
15S 21W	8	9N 22E	18	5N 17W	41
14S 29E	35	12N 21E	350	6N 18W	47
12S 23E	43	14S 11E	55	12S 23W	58
11S 22E	21	14S 8E	43	12S 30W	19
8S 18E	0	17S 3E	51	15S 38W	25
4S 17E	63	3S 5E	38		
2N 16E	62	7N 12W	58		

Reference (7, p. 56)

The epicenter is the part of the earth's surface directly above the focus of an earthquake.

FIGURE 9B: Earthquake Distribution Map

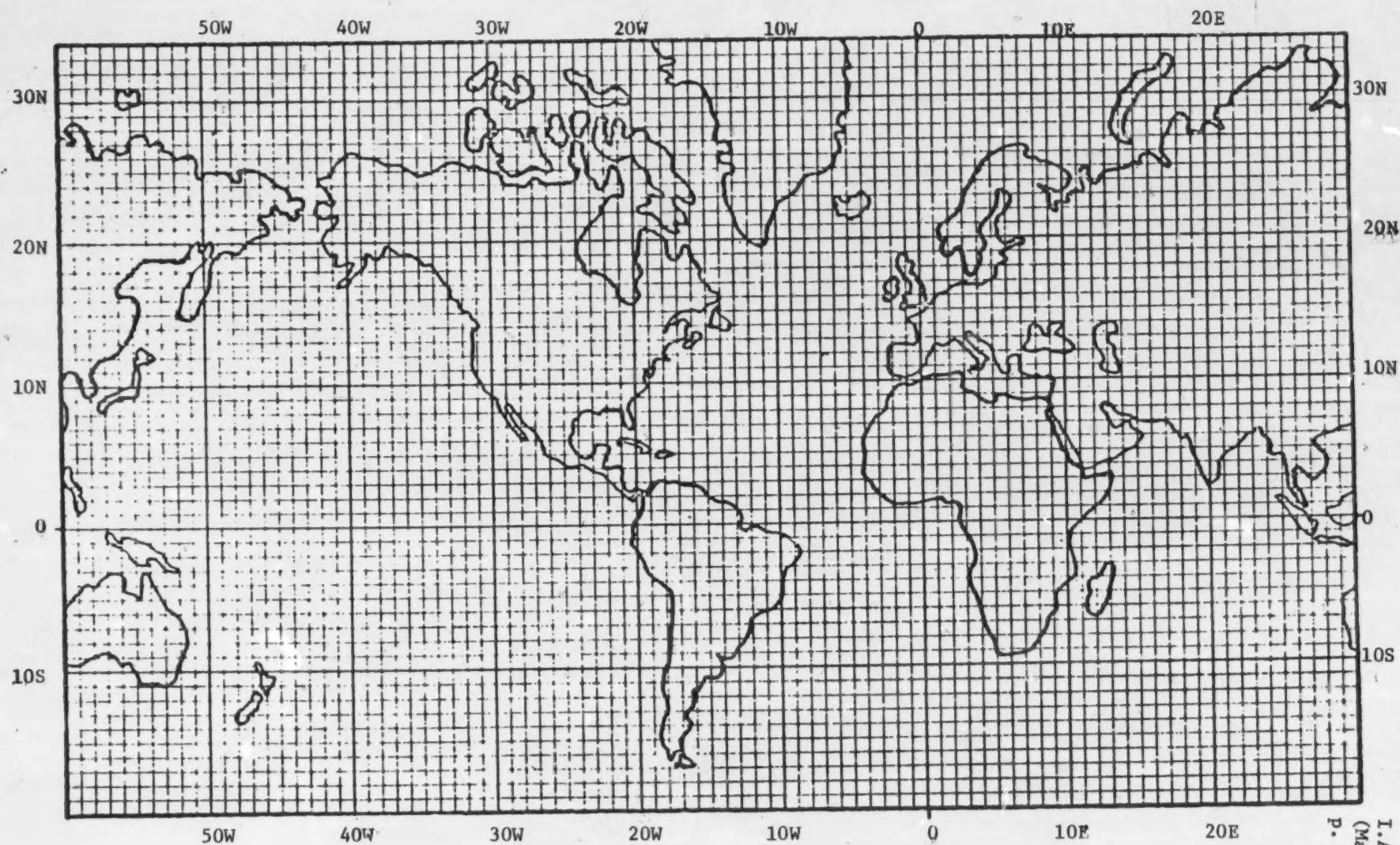


Figure 10A Earthquake Profile Data

The table below includes distance from a deep-sea trench and the depth below the surface, both in kilometers.

Distance	Depth	Distance	Depth	Distance	Depth
0	25	120	75	400	400
0	40	125	100	425	400
15	40	150	125	550	450
20	25	200	200	550	500
20	50	225	200	530	525
50	60	225	225	530	520
60	12	250	212	570	575
60	30	265	230	575	575
55	70	250	240	585	580
60	120	250	260	560	580
80	50	325	300	590	600
100	60	350	360	620	610

Figure 10B: Earthquake Distribution Profile

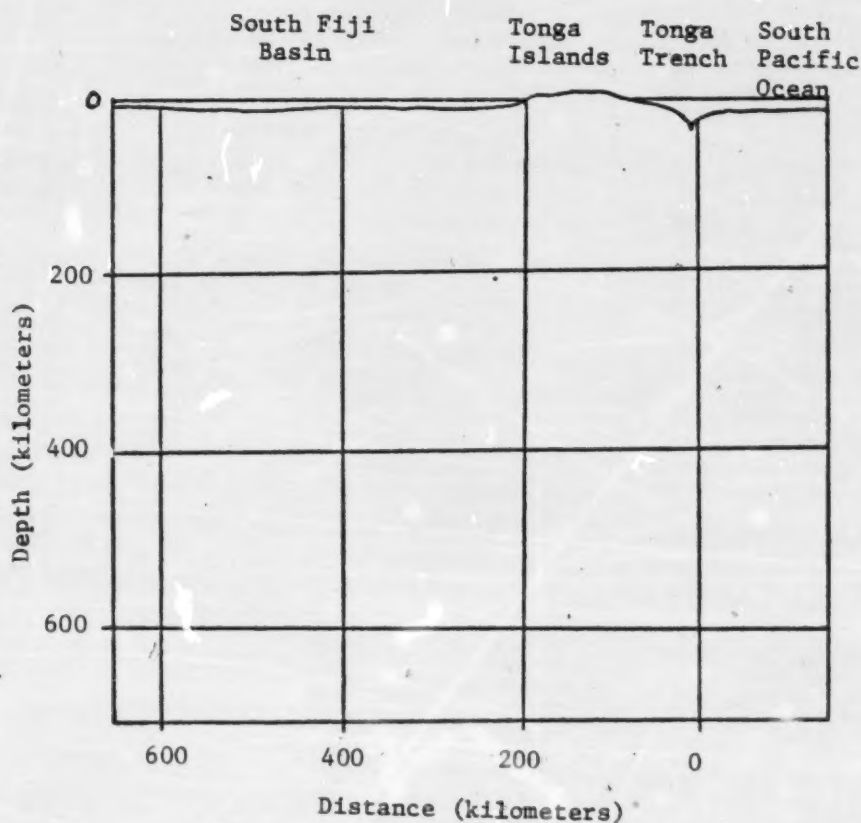


FIGURE 11A: Sediment Data from the South Atlantic

Distance (Km)	Age (millions of years)
1700	75
1500	65
1000	49
750	40
700	33
500	25
600	23
250	10

FIGURE 11B: Graph Paper for Figure 11A

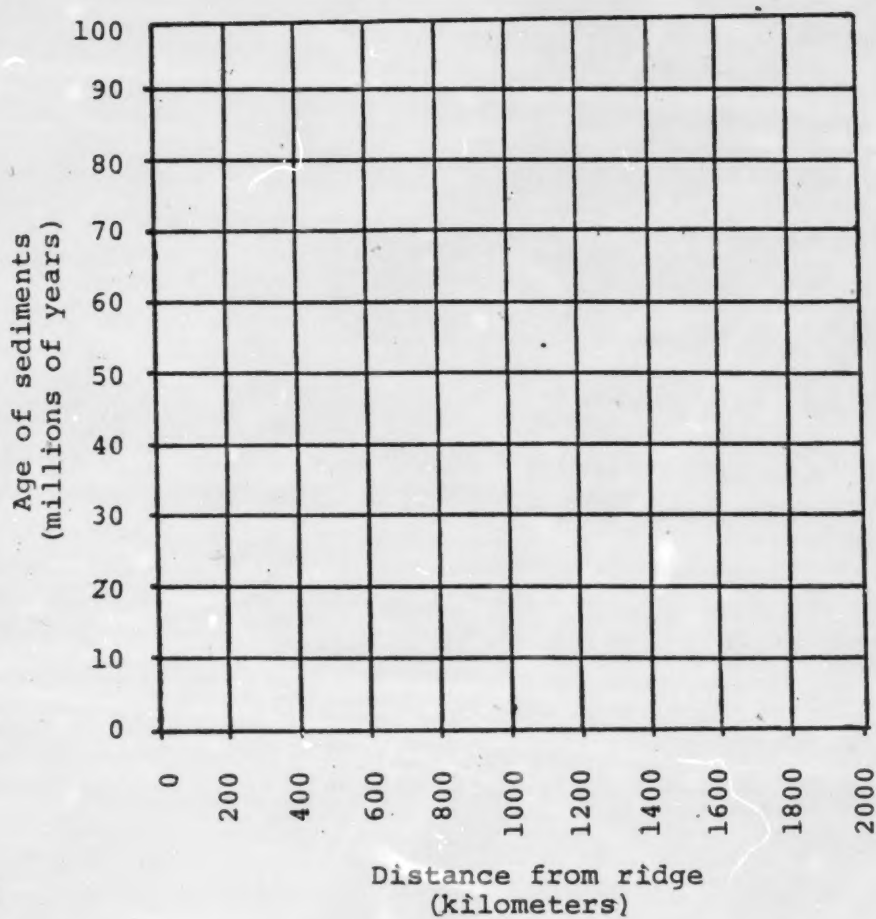
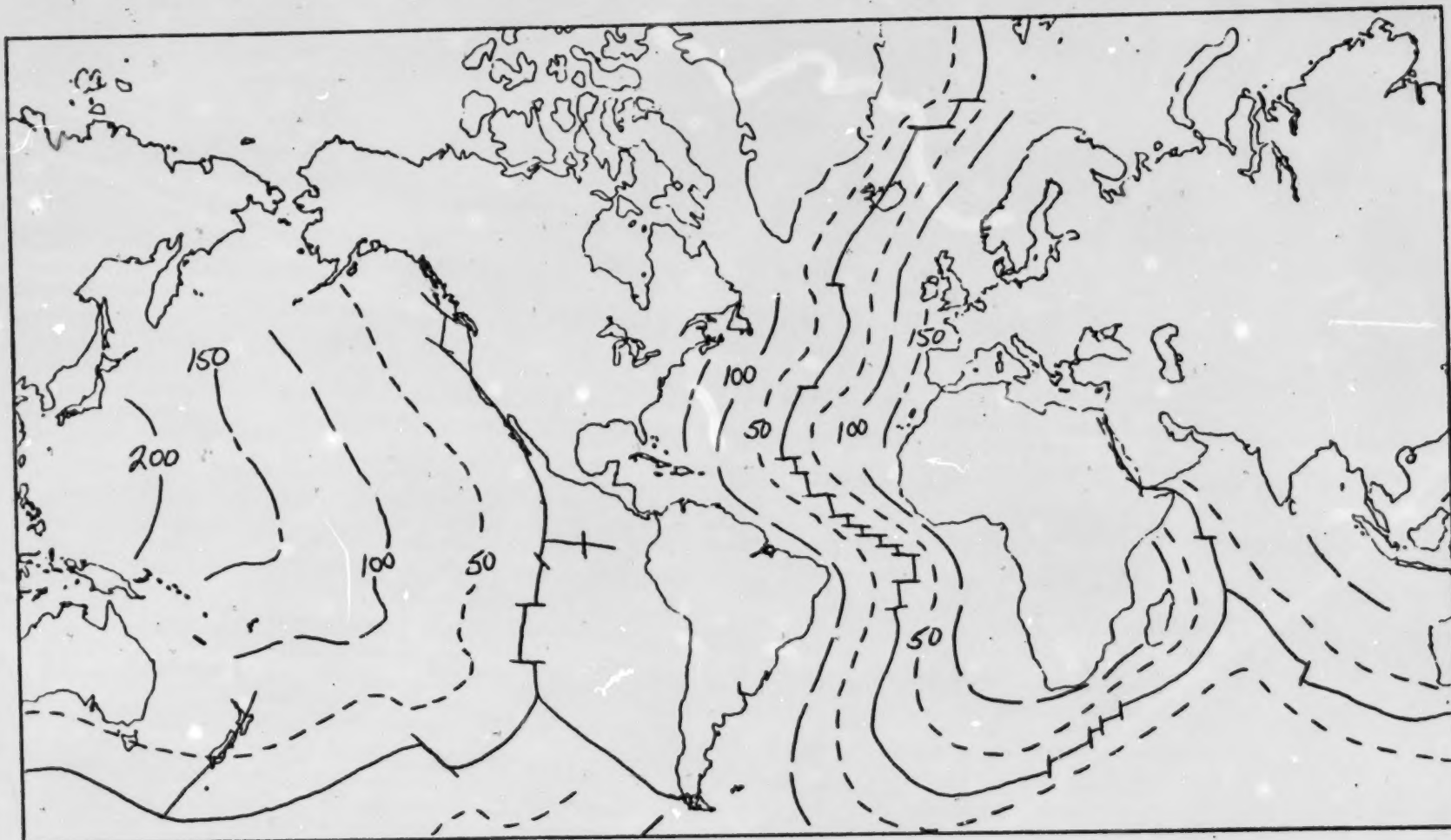


FIGURE 12: AGE OF THE EARTH'S CRUST UNDER THE OCEANS



Reference (5, p. 571)

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FIGURE 13: MAGNETIC REVERSALS

Figure 13A

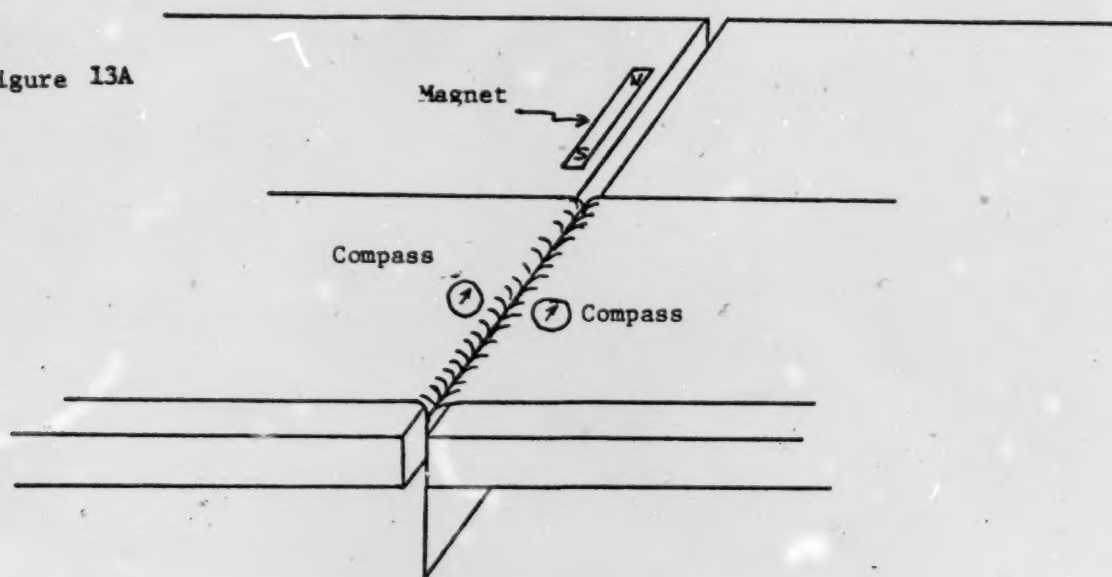


Figure 13B

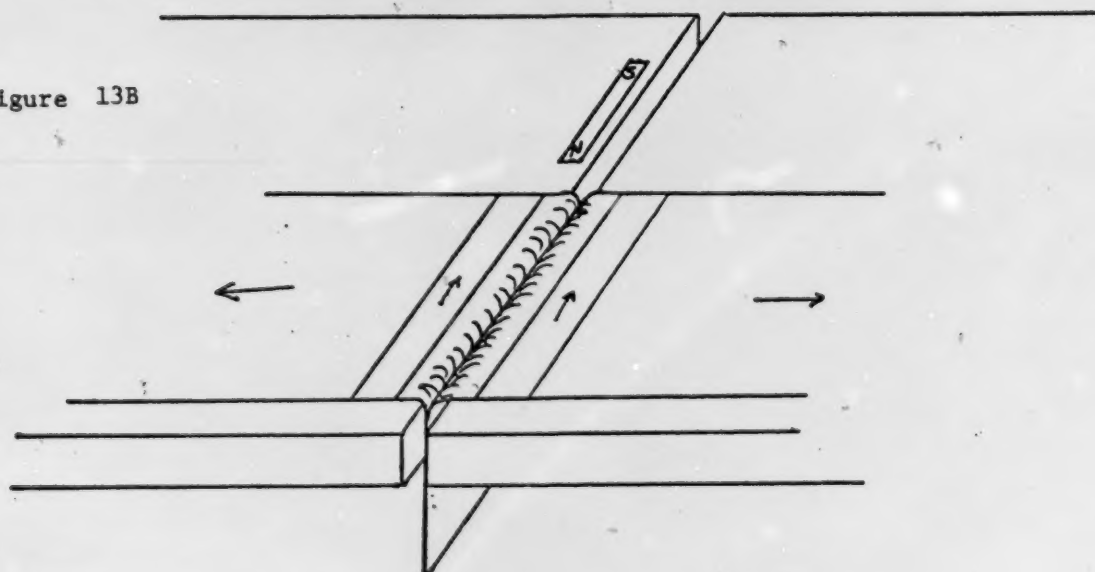
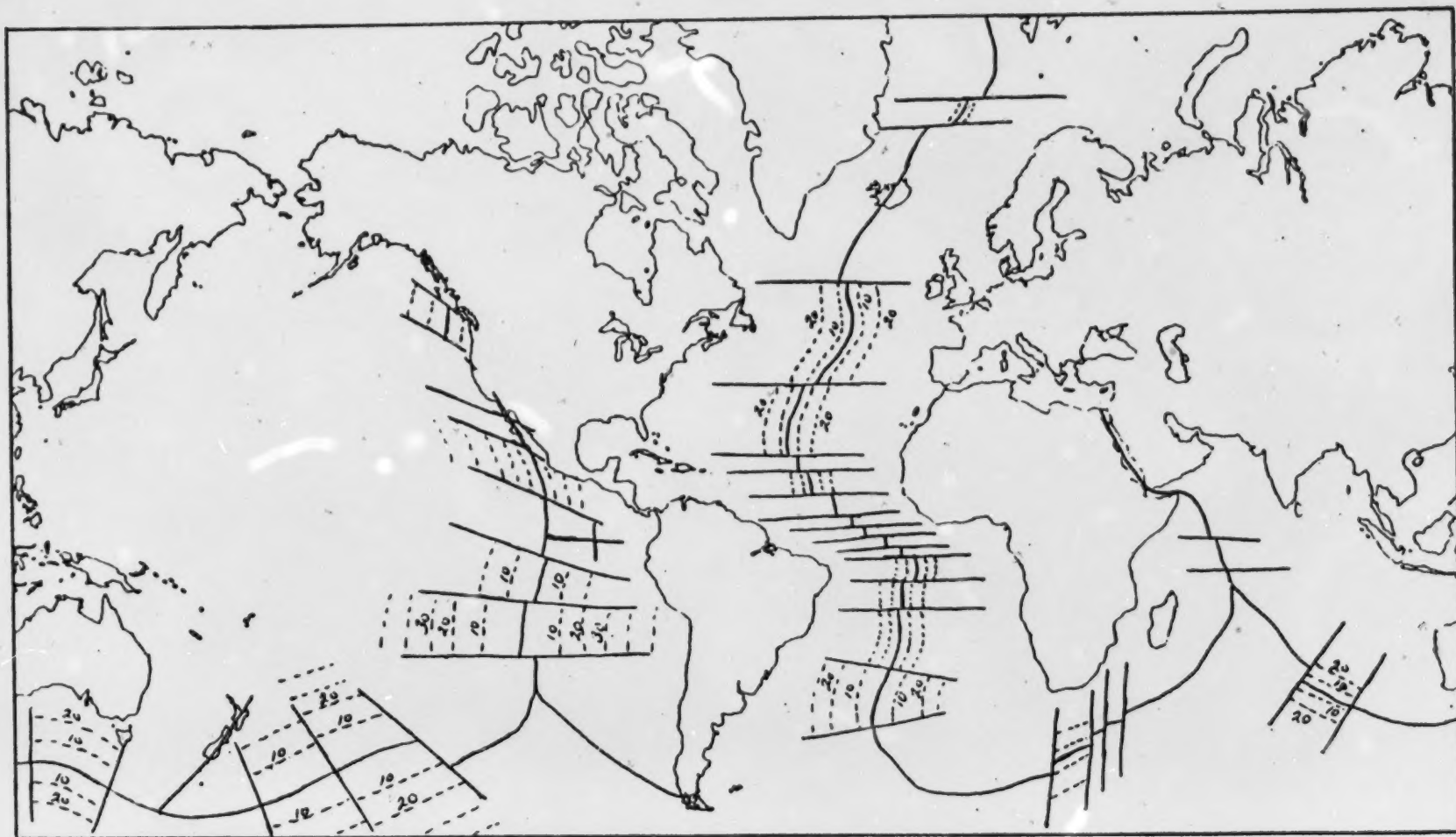


FIGURE 14: WORLD MAP OF MAGNETIC REVERSALS



10
20
Approximate age of ocean floor
in millions of years

SEA FLOOR SPREADING

Teacher's Guide

This guide includes notes on procedures, the purpose of each of the investigations, and the answers to the questions asked in the Student Material section of this learning experience. Figure 15, Collected Data from World Ocean Basins, and Figure 16, Movement Rates for Crustal Plates which are to be distributed to the students are included in this guide. These should not be distributed until the students reach the proper point in the section, The Earth's Puzzle--Part 2--Plate Tectonics, p. 12. Other than Figures 15 and 16, only supplementary figures for the instructor's use and those figures which the students were asked to complete are included in this guide (pp. 35-49). These figures are completed the way the students are asked to complete them.

SUBMARINE TOPOGRAPHIC FEATURES, pp. 4-5

Purpose: To enable the students to use the proper terms for topographic features found in the ocean basins and to locate these features in the ocean basins.

1. See Teacher's Guide Figure 1, p. 35.
2. Ridges are a continuous system of submarine mountains. See Figure 2, Ridges on the Ocean Basins, p. 14, or the National Geographic maps.
3. In the Atlantic, Indian and Arctic Oceans, the ridges are located in the middle of the ocean basins. In the Pacific Ocean, a ridge is located on the eastern and southern sides. See the National Geographic maps.
4. Yes. Trenches and island arcs are positioned next to one another. The trenches are found on the ocean side, with the island arcs positioned toward the continent. On the west coast of South and Central America where no islands are associated with trenches, the mountain ranges are analogous to island arcs. See Teacher's Guide Figure 3, p. 36.
5. Either the sea level has risen or the ocean basin has subsided.
6. In straight lines (approximately), the island arcs are generally oriented in SE to NW directions. See Teacher's Guide Figure 5A, p. 37.
7. Some island chains have submerged seamounts or guyots at their northwest ends and exposed islands at their southwest ends. In general, most seamounts and guyots in the Pacific are located in the northwest portion of the ocean. See the National Geographic map of the Pacific floor.
8. Because seamounts and guyots exist below the surface, this might suggest a relatively older age. Having lower elevation could be the result of longer exposure to erosional forces and/or subjection to longer periods of subsidence of the ocean floor. See Teacher's Guide Figure 5B, p. 38.

THE EARTH'S PUZZLE--Part 1, pp. 6-8

Purpose: To make the students aware of the one fact which first brought about the theory of continental drift--the "puzzle fit" relationship of several large land masses.

1. Yes. The east coast of the Western Hemisphere and the west coast of Europe and Africa seem to fit together. See Teacher's Guide Figure 6, p. 39.
2. Continents. Perhaps the present land masses of the world once fit together into one large land mass.
3. The majority of the students will probably not be able to answer this question sufficiently at this time. The answer is developed in the following questions.

The convection current investigation may be successful but may just as easily be a flop. A glass container which is wider and thinner-walled than a beaker should be used if possible. The students should be allowed to do this investigation on their own; however, walk around the classroom and watch their procedures and results. If one investigation does not work, let the student observe a more successful one and state why his own experiment failed.

4. The dye moves up over the flame because a heated substance is lighter and less dense, and thus rises over the same substance at a lower temperature.
5. Total movement should be over both burners and down in the middle.
6. See Teacher's Guide Figure 7A, p. 40
7. Over the rising convection current, the surface material is lifted; over a sinking convection current, the surface material is depressed.
8. The material on top is floating in the same direction as the current underneath. See Teacher's Guide Figure 7B, p. 40
9. Upward movement would suggest the formation of a ridge; downward movement would suggest the formation of a trench.
10. Wegener showed that the Americas, Europe and Africa could have been connected in the geologic past. If a ridge is an indicator of upward convective movement of the earth's interior, there should be lateral movement away from the ridge on both sides of the ridge. This may explain the similar coastlines and mid-ocean ridges in the North and South Atlantic.
11. See Teacher's Guide Figure 8, p. 41
12. Before the theory of moving continents could be strengthened, more information would have to be collected about the age of the rocks in ocean basins, the age of the rocks on the continents, the type of rock formations on the continents, the types of fossils on the continents, the types of rocks on both sides of the ridge systems, etc.

THE CRUST THAT CRACKS, pp. 8-9

Purpose: To show how earthquakes, evidence of crustal movement, correspond to areas of the ocean basins already discussed.

Although the epicenters given in Figure 9A, Earthquake Data, p. 21, could be given in latitude and longitude, the map has instead been superimposed over a piece of graph paper (ten squares equal one inch) to make the graphing easier for the students. The axes of the graph paper correspond to the equator and prime meridian. Any point to be plotted to the north of the equator is given a number followed by N; any point to be plotted south of the equator is indicated with an S. Points to be plotted to the east of the prime meridian are followed by E; points to be plotted west of the prime meridian are indicated with a W.

The students should be reminded that although the numbering system starts at the equator and the prime meridian, the numbers DO NOT represent degrees of latitude and longitude. They only represent a more convenient way of plotting the earthquakes.

Note: If you want more up-to-date information to use in this exercise, you might contact the Delaware Geological Survey located on the University of Delaware campus. At the time this learning experience was written, Mr. Kenneth Woodruff was the person to contact. You also might write the Smithsonian Institution, Center for Short-Lived Phenomena. The address is given below. Before more recent information can be added to this exercise, the locations of the earthquakes will have to be translated to the grid system used on Figure 9B, Earthquake Distribution Map, p. 22.

Smithsonian Institution
Center for Short-Lived Phenomena
60 Garden Street
Cambridge, MA 02138

Possible symbols the students could use for the three different depths of earthquakes are:

- | | |
|----------------|------------------|
| * Shallow | 0 Km to 69 Km |
| ○ Intermediate | 70 Km to 300 Km |
| △ Deep | 301 Km to 700 Km |

See Teacher's Guide Figure 9B, p. 42.

1. Most of the earthquakes occur around the edges of the Pacific Ocean. Earthquakes also occur in the Himalayas, in the Mediterranean Sea, and along the ocean ridge systems.
2. Around the Pacific Ocean.
3. Generally, shallow earthquakes occur farther out in the ocean; intermediate depth earthquakes occur closer to land; and deep earthquakes occur close to land or inland.
4. The occurrence of earthquakes indicates that the crust is unstable.
5. Yes.
6. Shallow focus earthquakes are nearest ridges; crustal movement must be near the surface.
7. Yes, there is a relationship. Shallow earthquakes occur nearest trenches; intermediate depth earthquakes occur under the island arcs; and deep earthquakes occur under the islands or continents. See Teacher's Guide Figure 10B, p. 43.
8. Earthquakes plunge into the crust under the island arcs at about a 45° angle.
9. Under the continents.
10. This suggests that the movement below the crust is downward and under the continents. (Students will need to rely on the idea of convection currents to answer this question.)
11. Any area around the Pacific Ocean will be suitable. Trenches and island arcs will be found in all. (Note: In South America, the island arc is replaced by a continental mountain range.)

OUR YOUTHFUL OCEANS, pp. 9-10

Purpose: To present further evidence supporting the theory of crust movement by discussing the following natural paradox: Although the earth is estimated to be 4.5 billion years old, the oldest rock and/or sediment found in any of the oceans does not exceed 200 million years in age.

See Teacher's Guide Figure 11B, p. 44

1. As distance from the ridge axis increases, the age of the sediments increases.
2. Near the continents.
3. No. About 4.4% of total age.

$$\frac{200 \times 10^6}{4.5 \times 10^9} \times 100\% = 4.4\%$$
4. Our present oceans are very young relative to total earth history.

SLOW DOWN AND LOOK BACK, pp. 10-11

Purpose: To review material that has been presented up to this point.

Although these answers are not intended to be collected, the students should spend enough time on this section to fully understand the relationships questioned.

- a. Island chains line up toward the northwest portion of the Pacific--roughly parallel to the estimated direction for sea floor movement.
- b. Guyots are located at the northwest end of most chains and in northwest sections of the Pacific Ocean basin. Guyots suggest age because they have subsided (sunk) hundreds of meters into the earth's crust, a process which occurs over millions of years. If sea floor movement occurs, then the oldest end of the chain would be the northwest end; the northwest is also the oldest portion of the Pacific Ocean basin.
- c. The coasts of the Americas, Europe and Africa fit together.
- d. Ridges suggest upward movement from under the earth's surface and lateral movement away from the ridge on the surface. Earthquakes with shallow foci occur when the crust is subjected to stress.
- e. Trenches suggest downward movement of the crust. If crust is directed downward, it will be subjected to stresses at various depths. These stresses will break (fracture) the crust allowing magma to seep to the surface and form volcanic islands all along the subductive zone (the region where the crust is pulled downward). See Teacher's Guide Figure 11C, p. 45.
- f. If new crust is created along the ridge axes, then as the distance increases from ridge axes, the age of the rock will also increase.
- g. Convection movement upward creates ridges; convection movement downward creates trenches.

Use Figure 15, p. 46 as a teacher guide for this activity. DO NOT DISTRIBUTE FIGURE 15 TO THE STUDENTS AT THIS TIME.

CONFIRMATION, pp. 11-12

Purpose: To add further support to the theory of crustal movement by using the earth's magnetic field as evidence.

1. The compasses have changed direction.
2. It would cause the iron atoms to line up in a reversed manner.
3. Yes.
4. The rate of spreading on each side of the ridge axis for a given location is the same.
5. Yes. There is only one way such reversals can be explained. By their existence, they indicate sea floor spreading from ridge axes.

THE EARTH'S PUZZLE--Part 2--Plate Tectonics, p. 12

Purpose: To introduce the students to the concept of plate tectonics and have them speculate on future movements of crustal plates.

Figure 15, Collected Data from World Ocean Basins, p. 46, should be distributed to the students at this time.

1. The answer will vary; it should be six or seven, as shown on Teacher's Guide Figure 15, p. 47.

Figure 16, Movements for Crustal Plates, p. 48, should be distributed to the students at this time.

In constructing the new puzzle of the earth 50 million years into the future, the students may want to cut out all new parts to match the maps they have been using. For this reason, have a sufficient number of blank maps on hand.

See Teacher's Guide Figure 16, p. 49.

2. The Pacific Ocean is becoming smaller and both the Atlantic and Indian Oceans are becoming larger.
3. The Pacific Ocean is older. It is an ancient sea that is being "squeezed out" by the younger Atlantic Ocean.

The evidence presented above to support the theory of plate tectonics was limited only to the evidence found in the ocean basins. Data from the seven continents further support the theory of plate tectonics. For example, geological and paleontological matches have been established across the Atlantic and Indian Oceans.

If you wish to add this type of evidence to this learning experience, it is suggested that you read from any of the references listed as good or excellent on the reference list, pp. 33-34. An excellent book on the complete scope crustal movements is Continental Drift, by Don and Maureen Tarling. This book briefly covers a wide variety of topics in support of the crustal movement theory and is written in a non-technical manner so that the high school science student will have little or no trouble understanding it.

The articles in Scientific American are also very good; they more fully explain the evidence presented in this lesson. These articles concentrate on the evidence taken from the ocean basins and examine it in considerable depth. As background for the material presented in this learning experience they are invaluable.

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2. Dewey, John F. 1972. Plate tectonics. Scientific American May: 226(5), 56-67. GOOD.
3. Dietz, Robert S. and John C. Holden. 1970. The breakup of Pangaea. Scientific American. October: 223(4), 30-41. EXCELLENT.
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14. Vine, F. J. 1970. Sea floor spreading and continental drift. Journal of Geologic Education. March: 18, 87-90.
15. Vine, F. J. 1969. Sea floor spreading--new evidence. Journal of Geologic Education. February: 17, 6-15.

16. Weyl, Peter K. 1970. Oceanography. John Wiley & Sons, Inc., New York. GOOD.
17. Wilson, J. Tuzo. 1963. Continental drift. Scientific American. April: 208(4), 8-9.

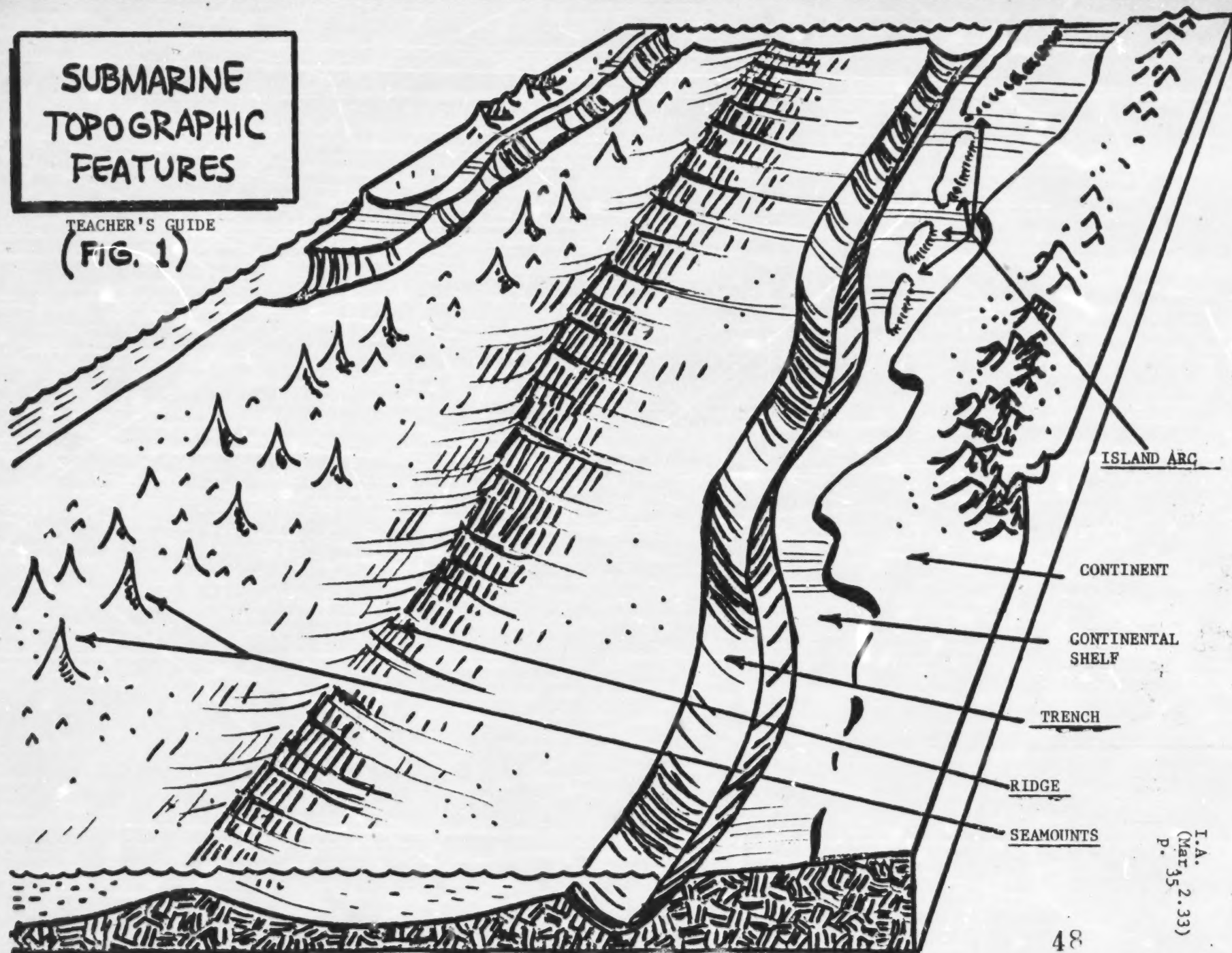
Maps

The National Geographic maps referred to earlier in this learning experience are found as supplements to the articles listed below. All four maps are excellent.

1. -----1969. Face and floor of the "peaceful" sea. National Geographic. October: 136(4), 496-499.
2. Matthews, Samuel W. 1967. Science explores the monsoon sea. National Geographic. October: 132(4), 554-575.
3. -----1968. Two faces of the Atlantic. National Geographic. June: 133(6), 794-797.
4. -----1971. Unveiling an ocean of ice. National Geographic. October: 140(4), 518-519.

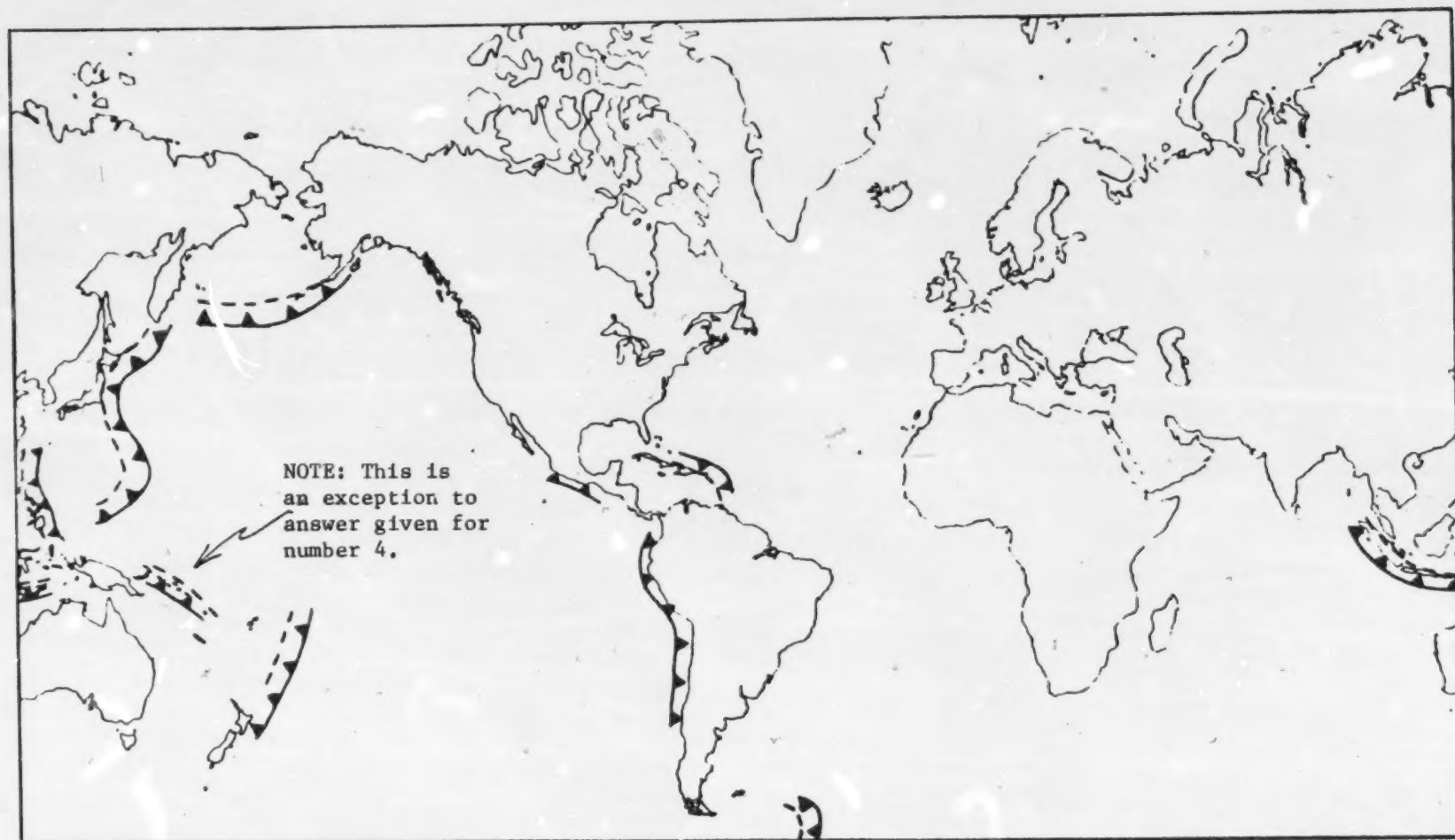
SUBMARINE TOPOGRAPHIC FEATURES

TEACHER'S GUIDE
(FIG. 1)



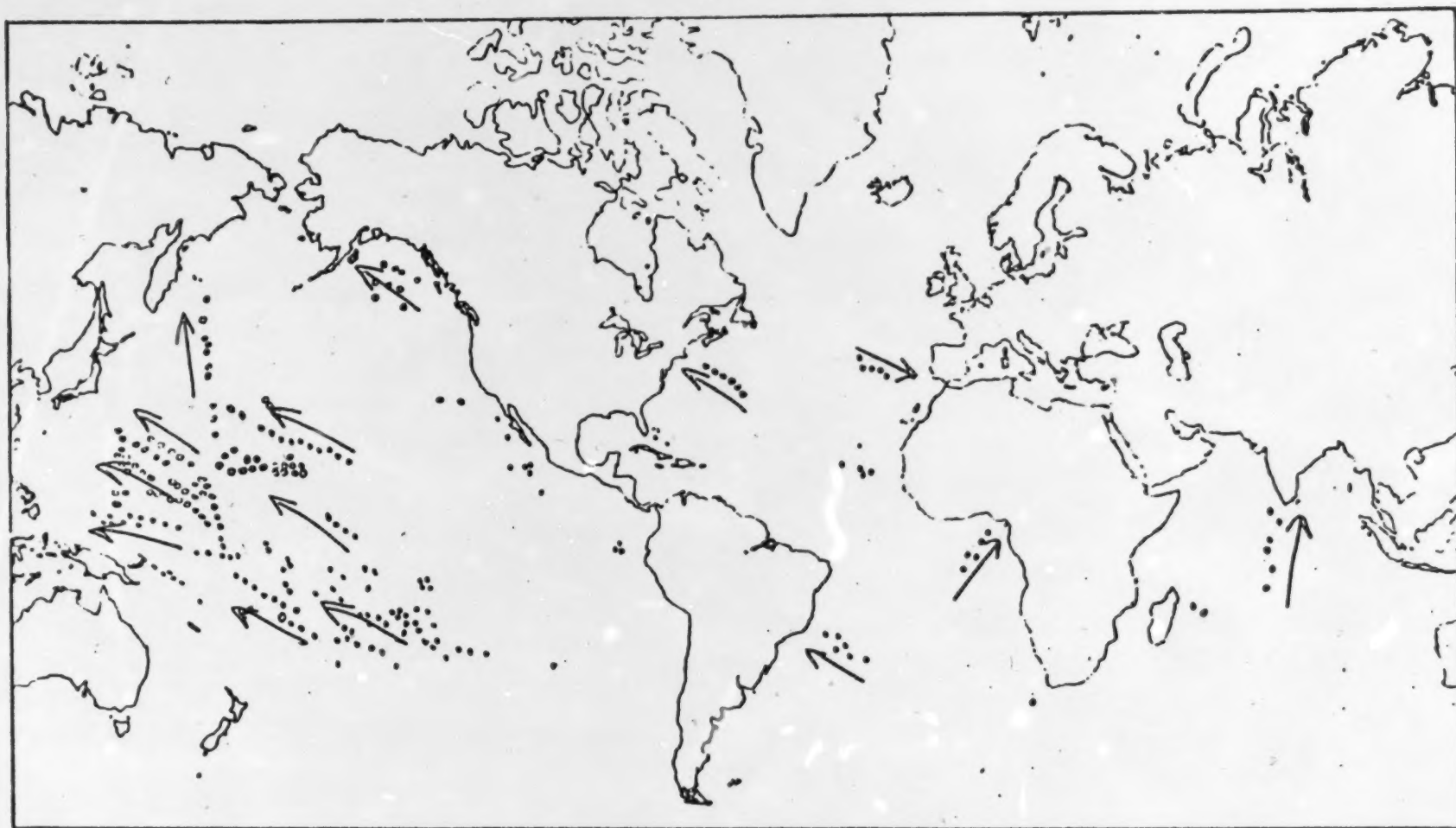
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TEACHER'S GUIDE FIGURE 3: ISLAND ARCS AND DEEP-SEA TRENCHES



- - - - - Island arcs
 —▲—▲—▲— Trenches
 Reference (2, pp. 56-57)

TEACHER'S GUIDE FIGURE 5A: ISLAND AND SEAMOUNT CHAINS

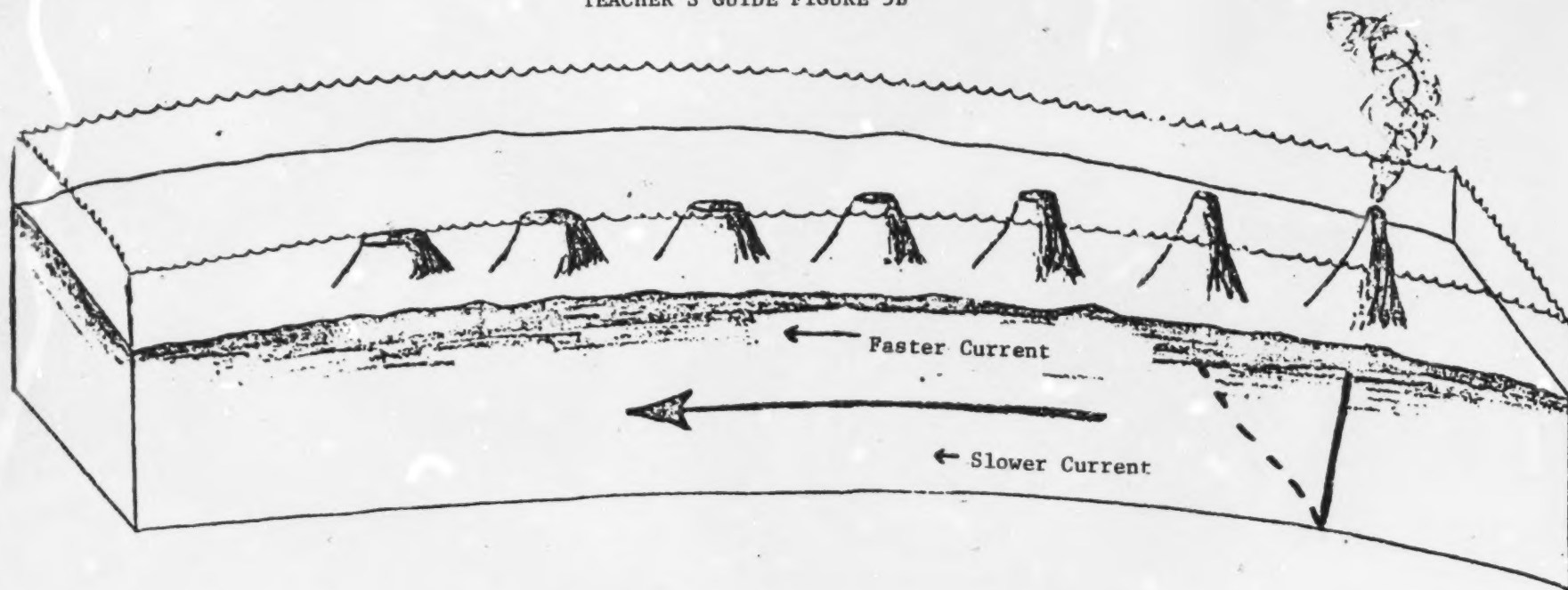


ooo Seamount Chains (This includes guyots within seamount chains, and guyot chains.)

... Island Chains

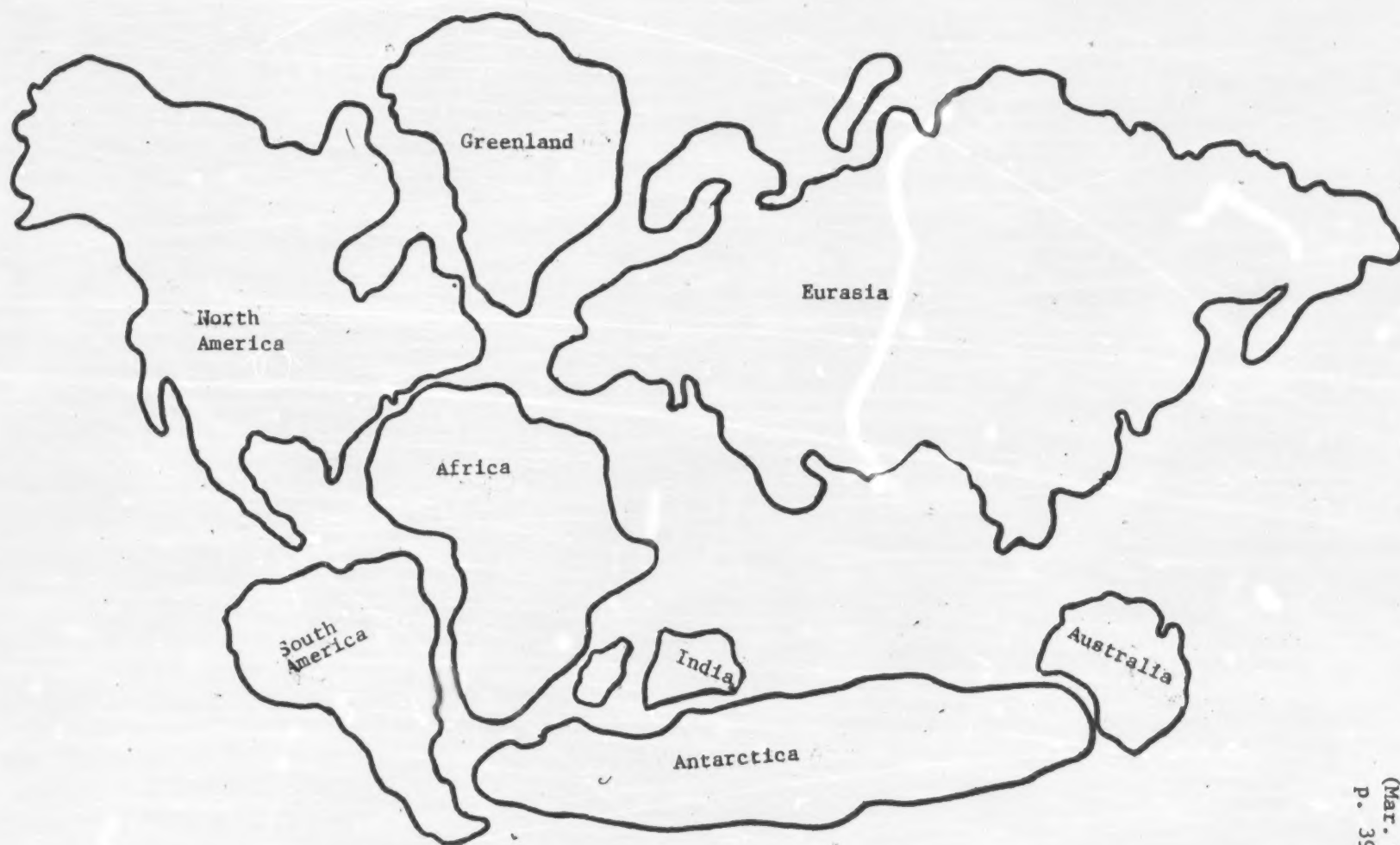
References (9, pp. 300-322)
(5, pp. 496-497)

TEACHER'S GUIDE FIGURE 5B



Chains of islands, seamounts, and/or guyots are progressively older in the direction of the arrow. The differential crustal current moves old volcanoes away from the source vent of magma, while new volcanoes form over the source. Reference (17, p. 9)

TEACHER'S GUIDE FIGURE 6: PUZZLE PARTS ASSEMBLED



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TEACHER'S GUIDE FIGURE 7: CONVECTION CURRENTS

Figure 7A: Convection Current Circulation

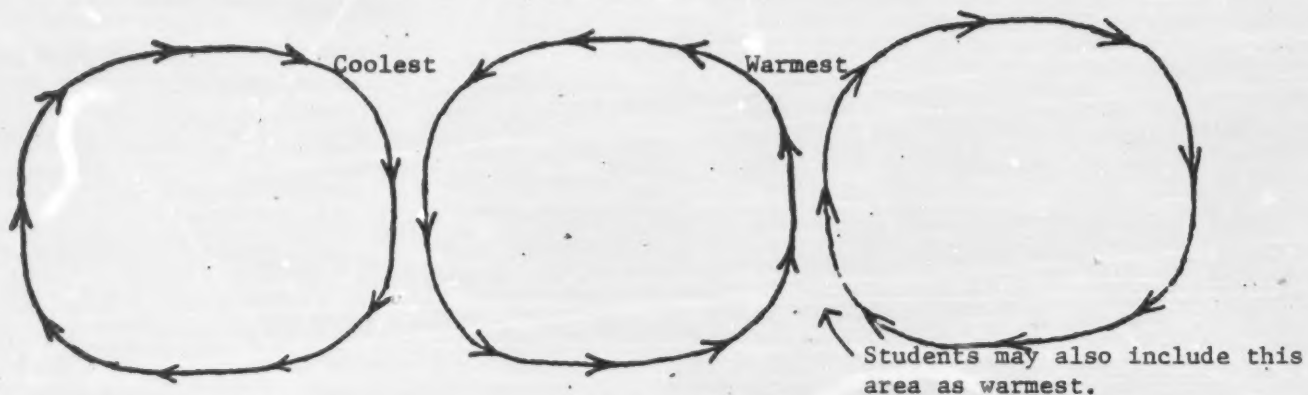
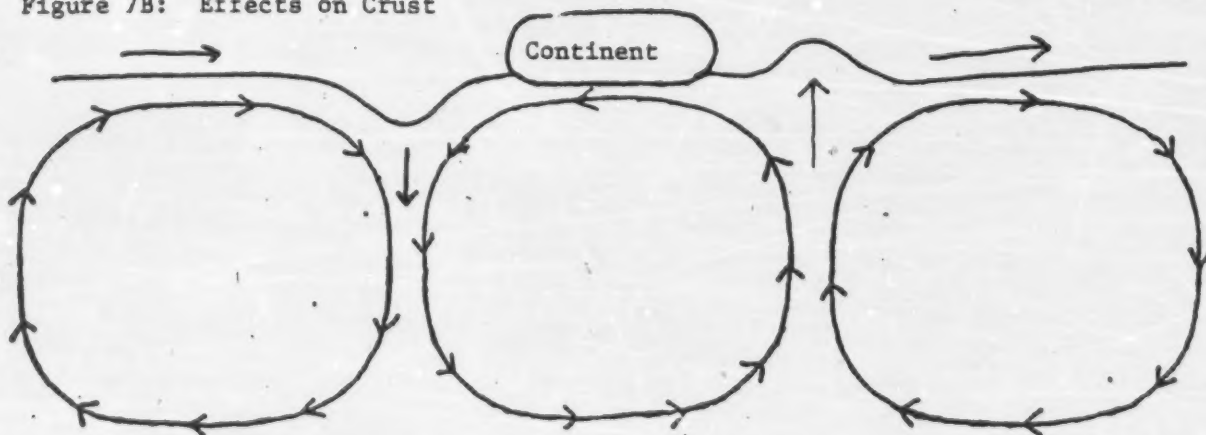
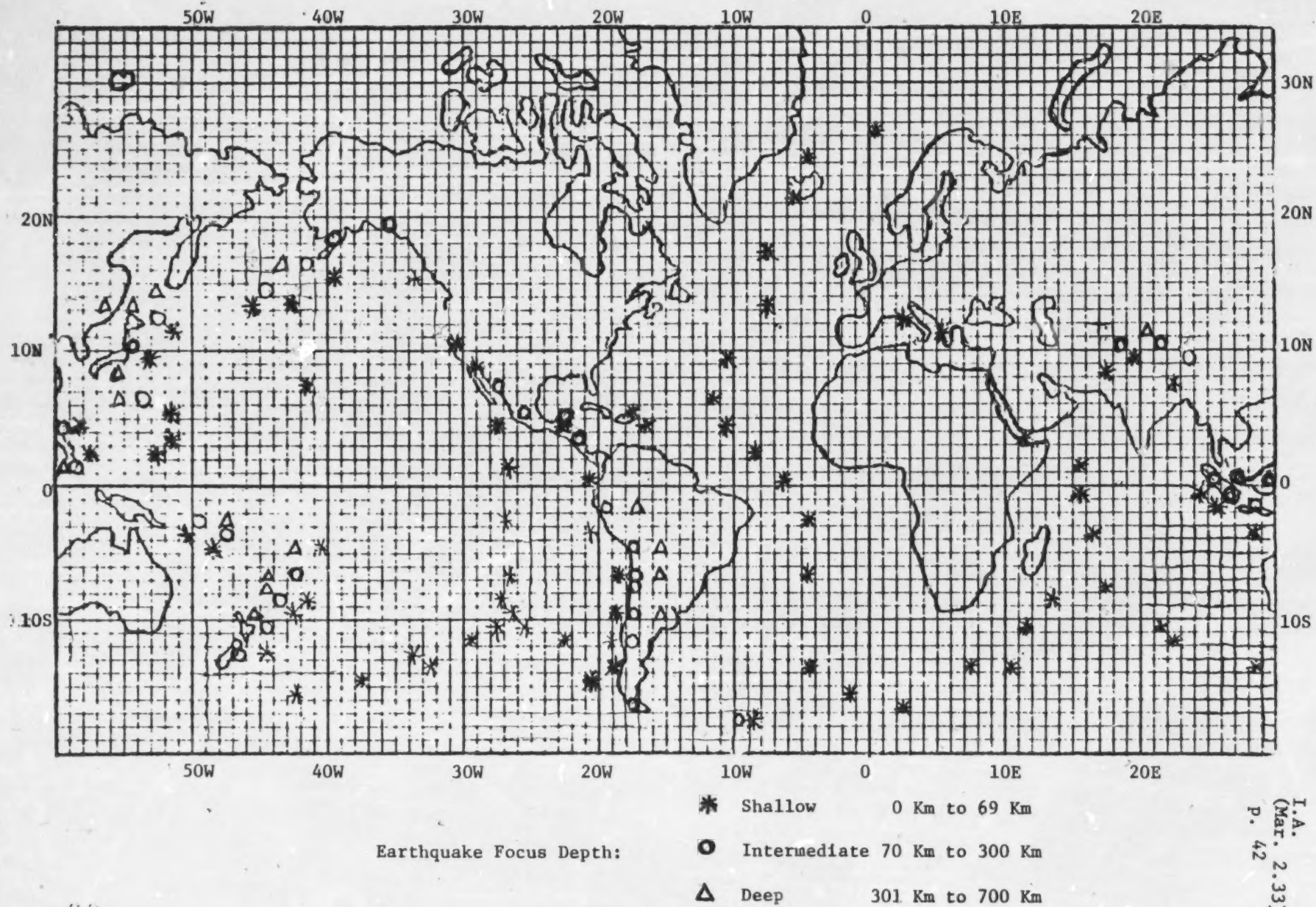


Figure 7B: Effects on Crust



TEACHER'S GUIDE FIGURE 9B: EARTHQUAKE DISTRIBUTION MAP



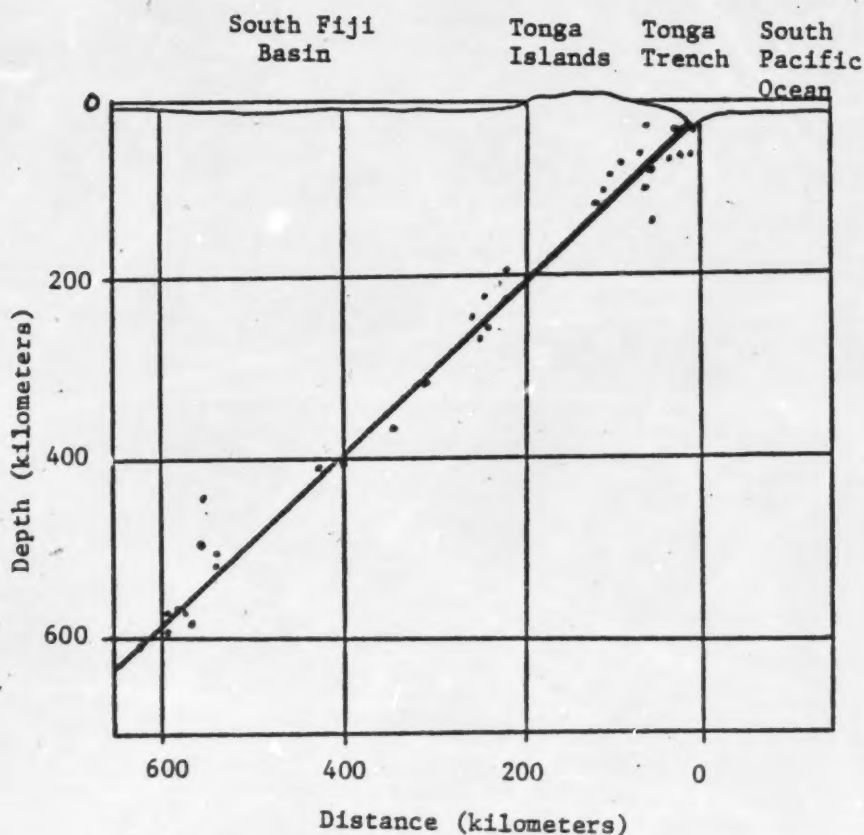
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Figure 10A Earthquake Profile Data

The table below includes distance from a deep sea trench and the depth below the surface, both in kilometers.

Distance	Depth	Distance	Depth	Distance	Depth
0	25	120	75	400	400
0	40	125	100	425	400
15	40	150	125	550	450
20	25	200	200	550	500
20	50	225	200	530	525
50	60	225	225	530	520
60	12	250	212	570	575
60	30	265	230	575	575
55	70	250	240	585	580
60	120	250	260	560	580
80	50	325	300	590	600
100	60	350	360	620	610

Teacher's Guide

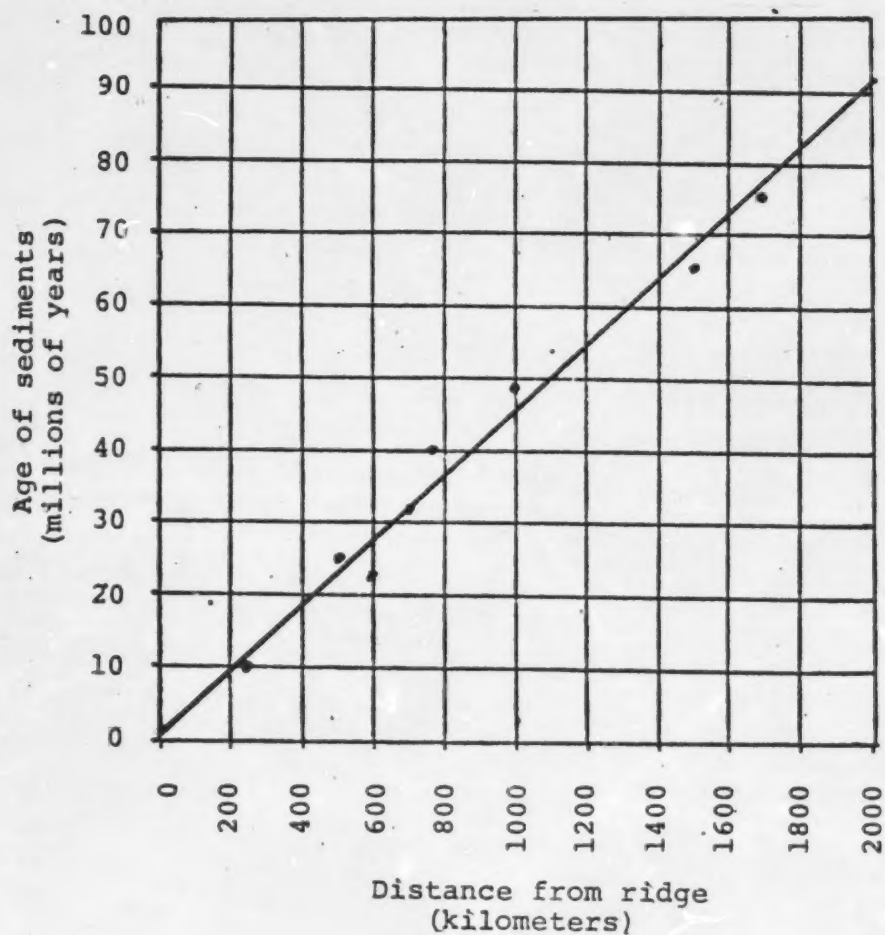
Figure 10B: Earthquake Distribution Profile

TEACHER'S GUIDE

FIGURE 11A: Sediment Data from the South Atlantic

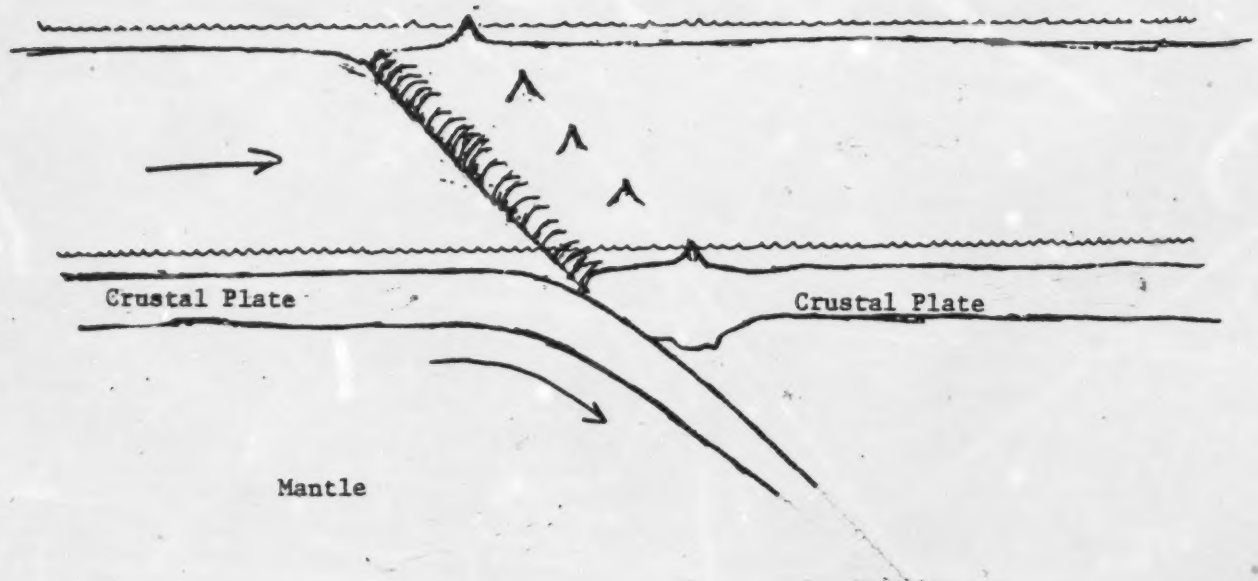
Distance (Km)	Age (millions of years)
1700	75
1500	65
1000	49
750	40
700	33
500	25
600	23
250	10

TEACHER'S GUIDE FIGURE 11B



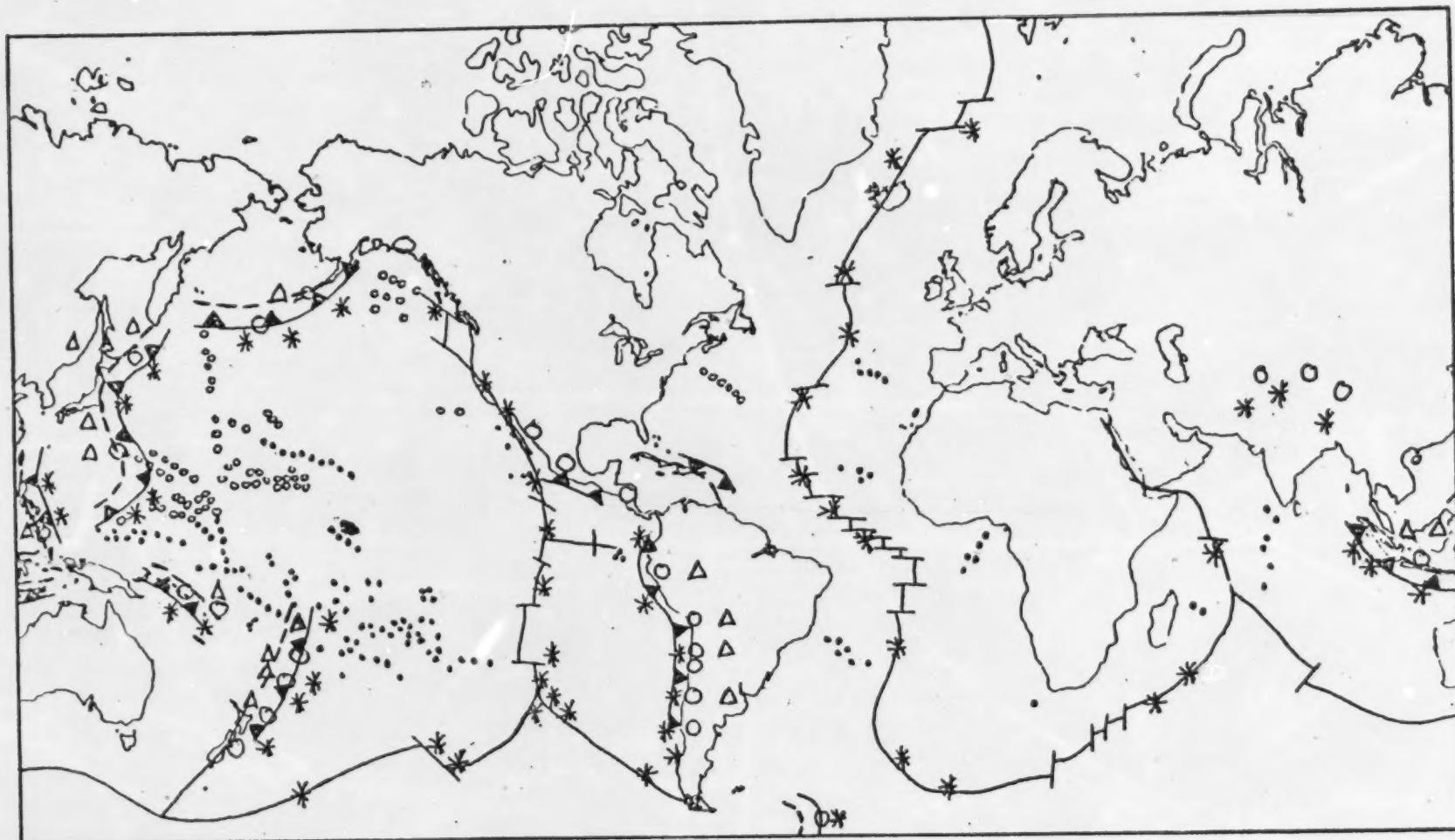
TEACHER'S GUIDE FIGURE 11C

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Reference (10, p. 129)

FIGURE 15: COLLECTED DATA FROM WORLD OCEAN BASINS

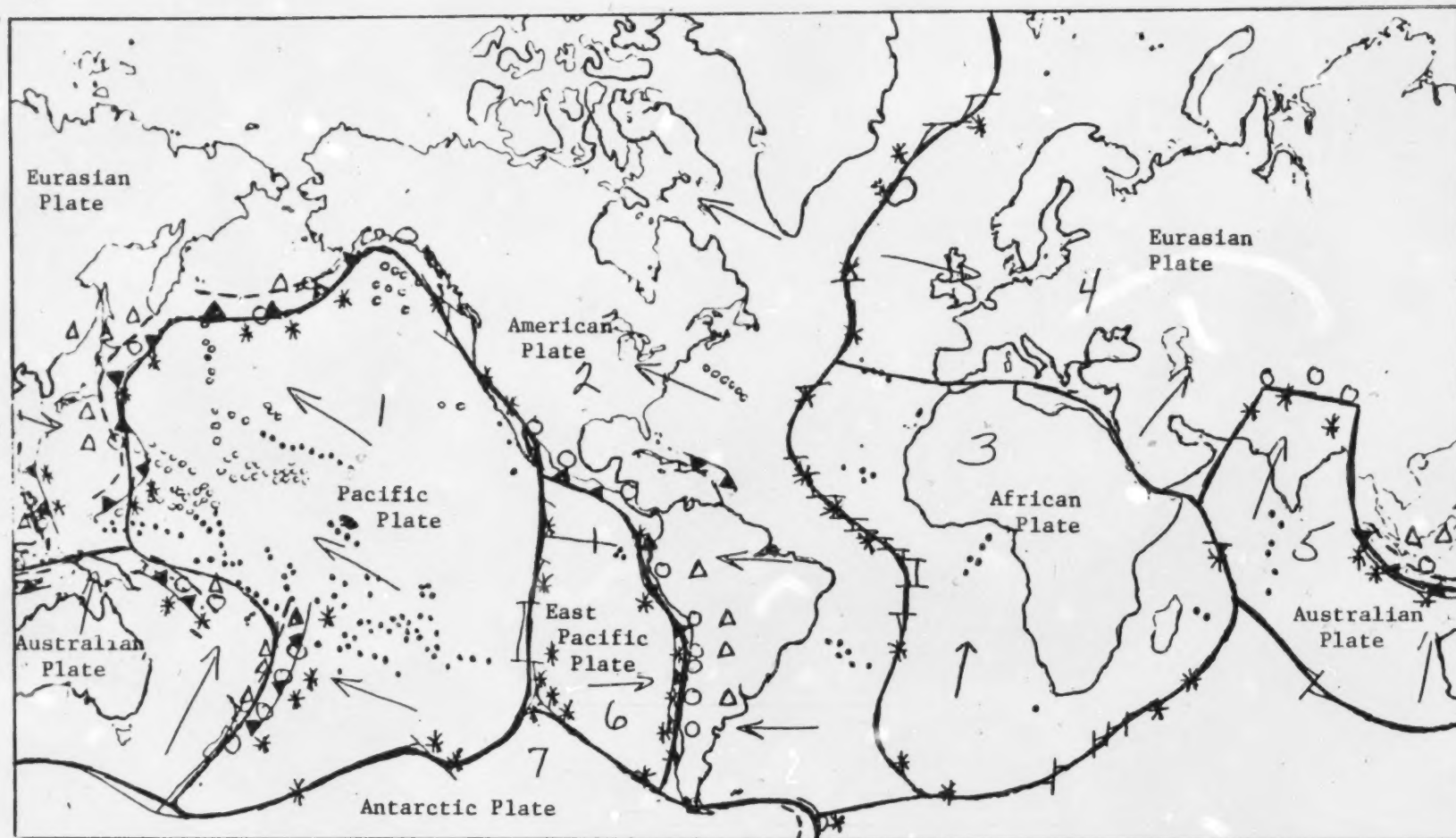


- * Shallow--0 Km to 69 Km
- Intermediate--70 Km to 300 Km
- △ Deep--301 Km to 700 Km

- Island arcs
- ▲ Trenches
- Seamount chains
- Island chains
- ⊥ Ridges with transform faults

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TEACHER'S GUIDE FIGURE 15: COLLECTED DATA FROM WORLD OCEAN BASINS



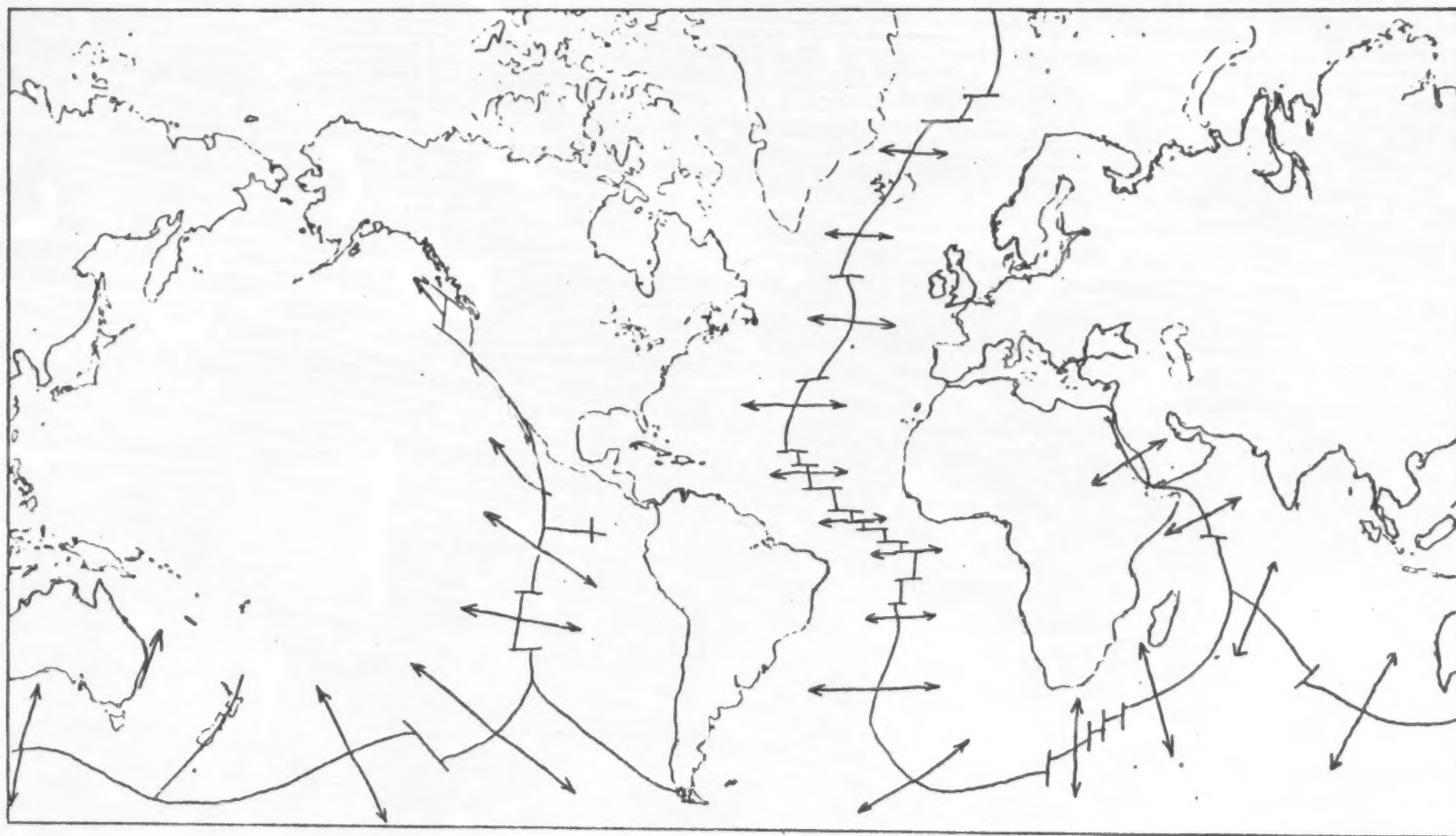
*Shallow 0 Km to 69 Km
 Earthquake Focus Depth: ○ Intermediate 70 Km to 300 Km
 △ Deep 301 Km to 700 Km

--- Island arcs
 ▲ Trenches
 ○○○ Seamount chains
 Island chains
 - - - - Ridges with transform faults

Reference (15, p.6)

I.A.
 (Mar. 2.33)
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FIGURE 16: MOVEMENTS FOR CRUSTAL PLATES



Reference (17, p. 6)

